Monitoring Land-Atmosphere CO_2 Exchange: The SMAP Level 4 Carbon (L4C) Product

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Water & Ecological Strategy

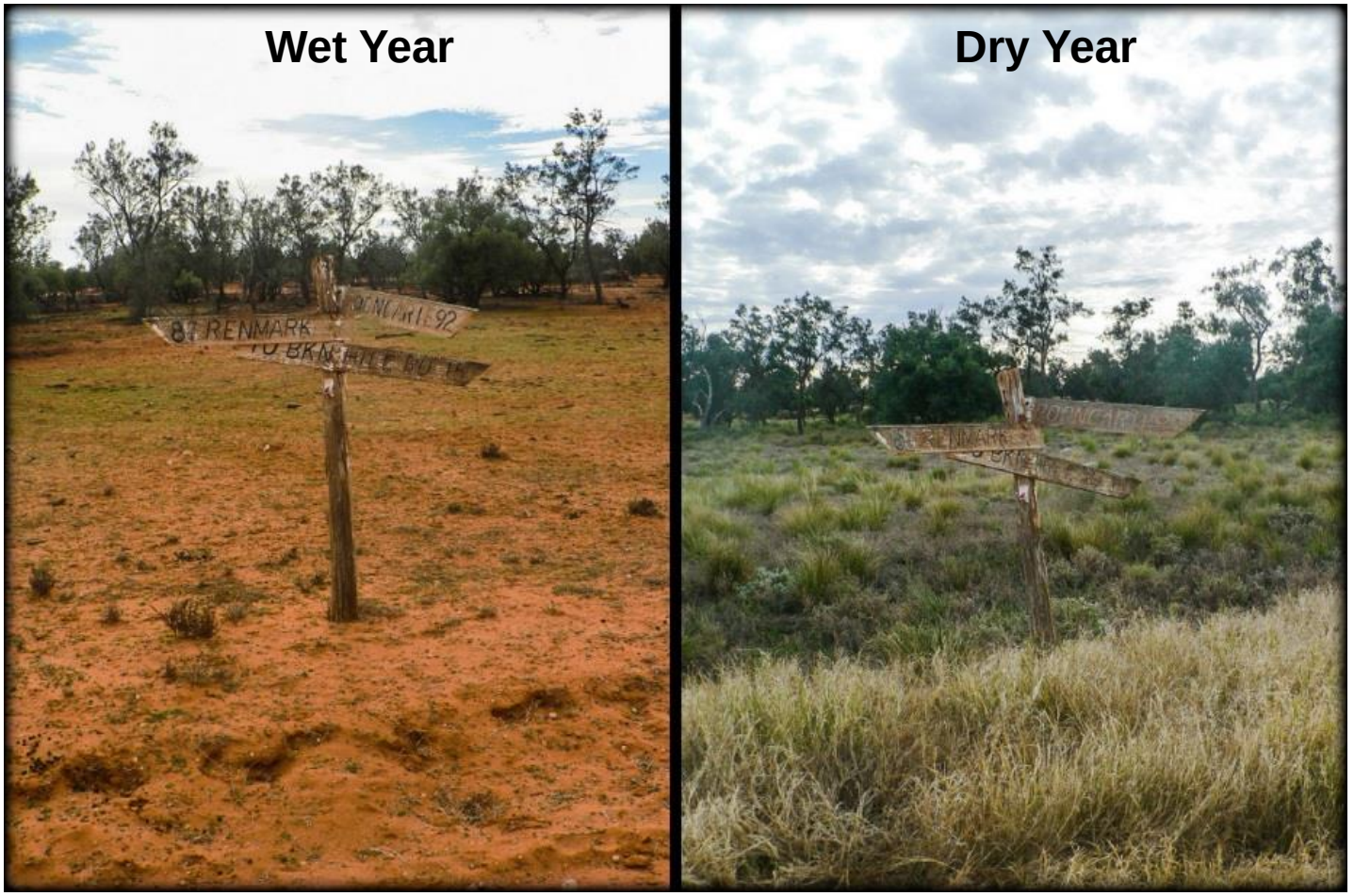
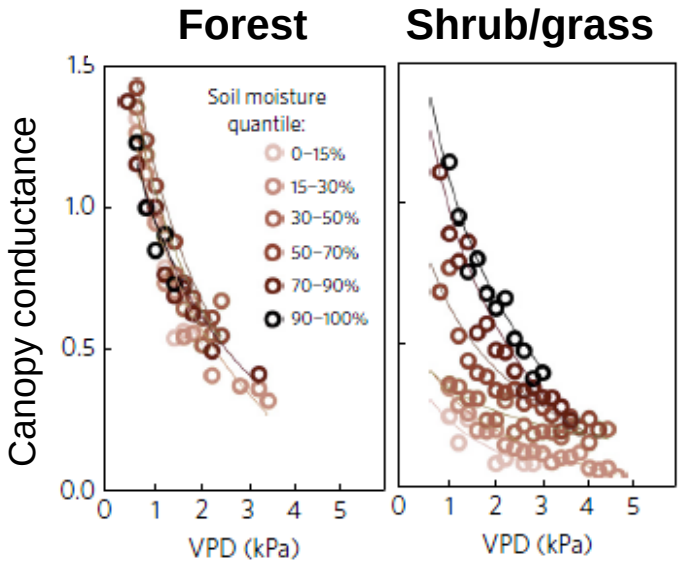
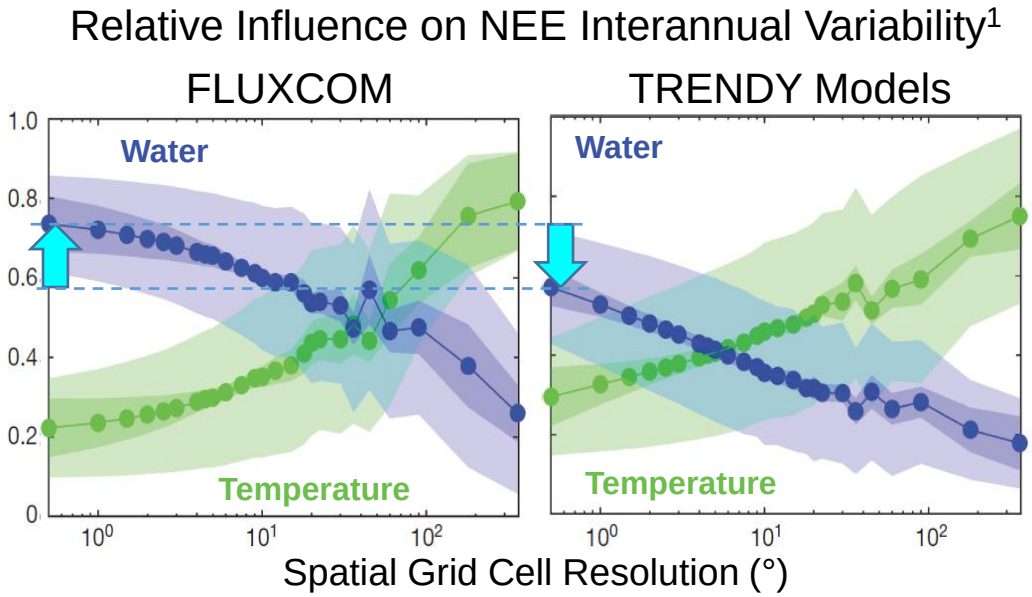


Photo Credit: Samantha Travers https://ianluntecology.com/2014/12/21/repeat-photo-gallery

Role of Soil Moisture from Ecosystem to Global Scale

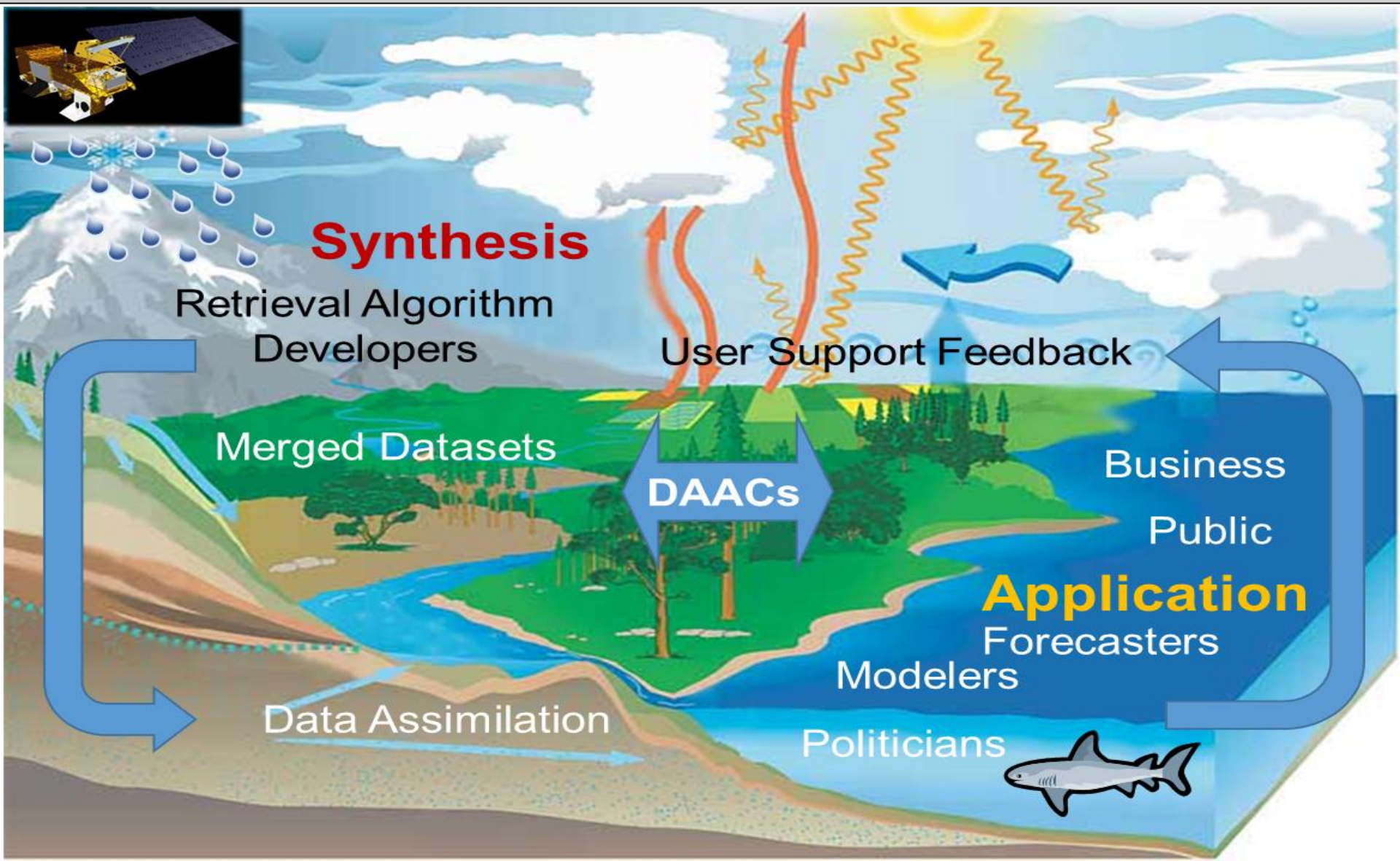




- Plant production (GPP) and ecosystem respiration respond differently to water availability.[1]
- Soil moisture and VPD have differing influences on GPP drought response.[2]
- Water availability controls inter-annual variability in land-atmosphere CO_2 exchange.[3]

[1]Jung, *Nature* 2017; [2]Novick, *Nature Clim. Change* 2016; [3]Poulter *Nature* 2014

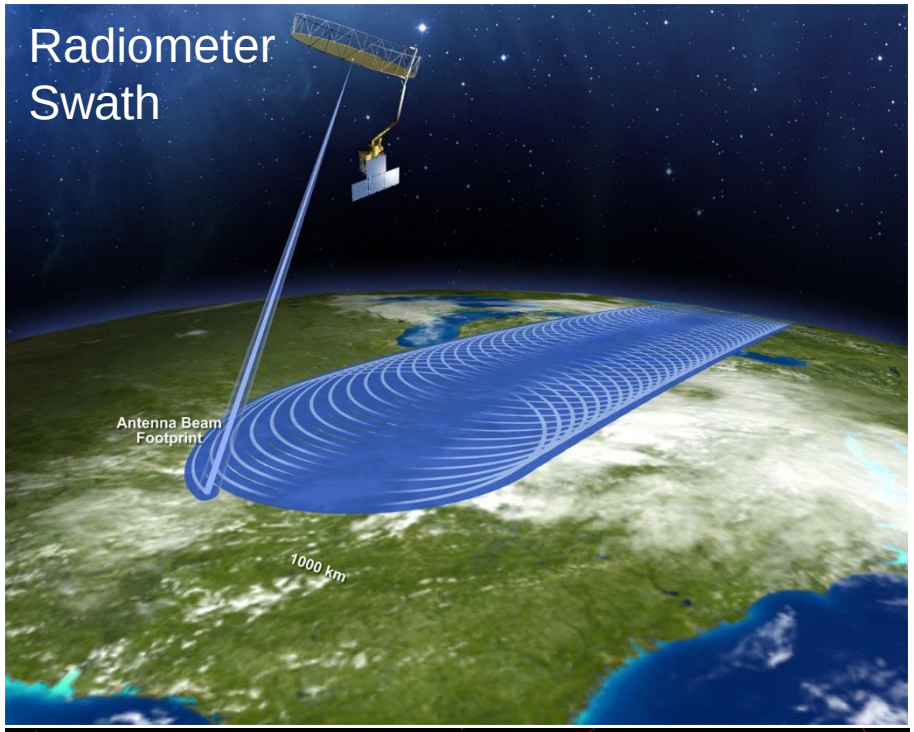
The Data Cycle

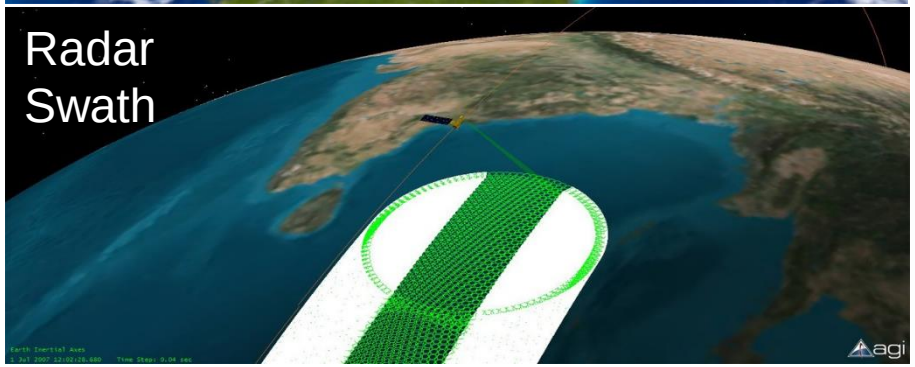


Research Questions

- Does soil moisture improve skill for estimating net ecosystem CO_2 exchange (NEE)?
- What is the incremental value of using SMAP information for estimating NEE?
- What can these estimates tell us about NEE response to recent soil moisture variability?

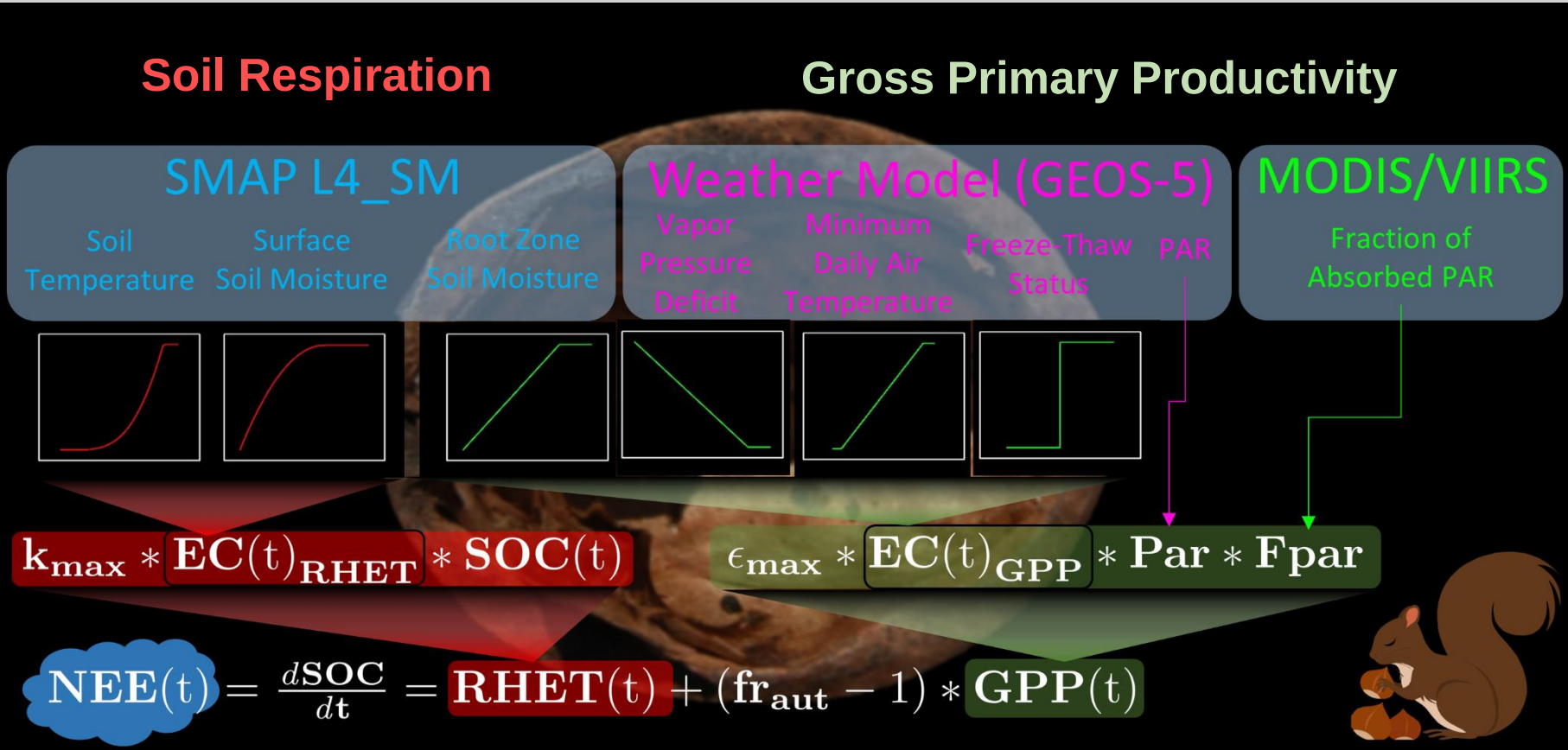
Soil Moisture Active-Passive (SMAP) Mission





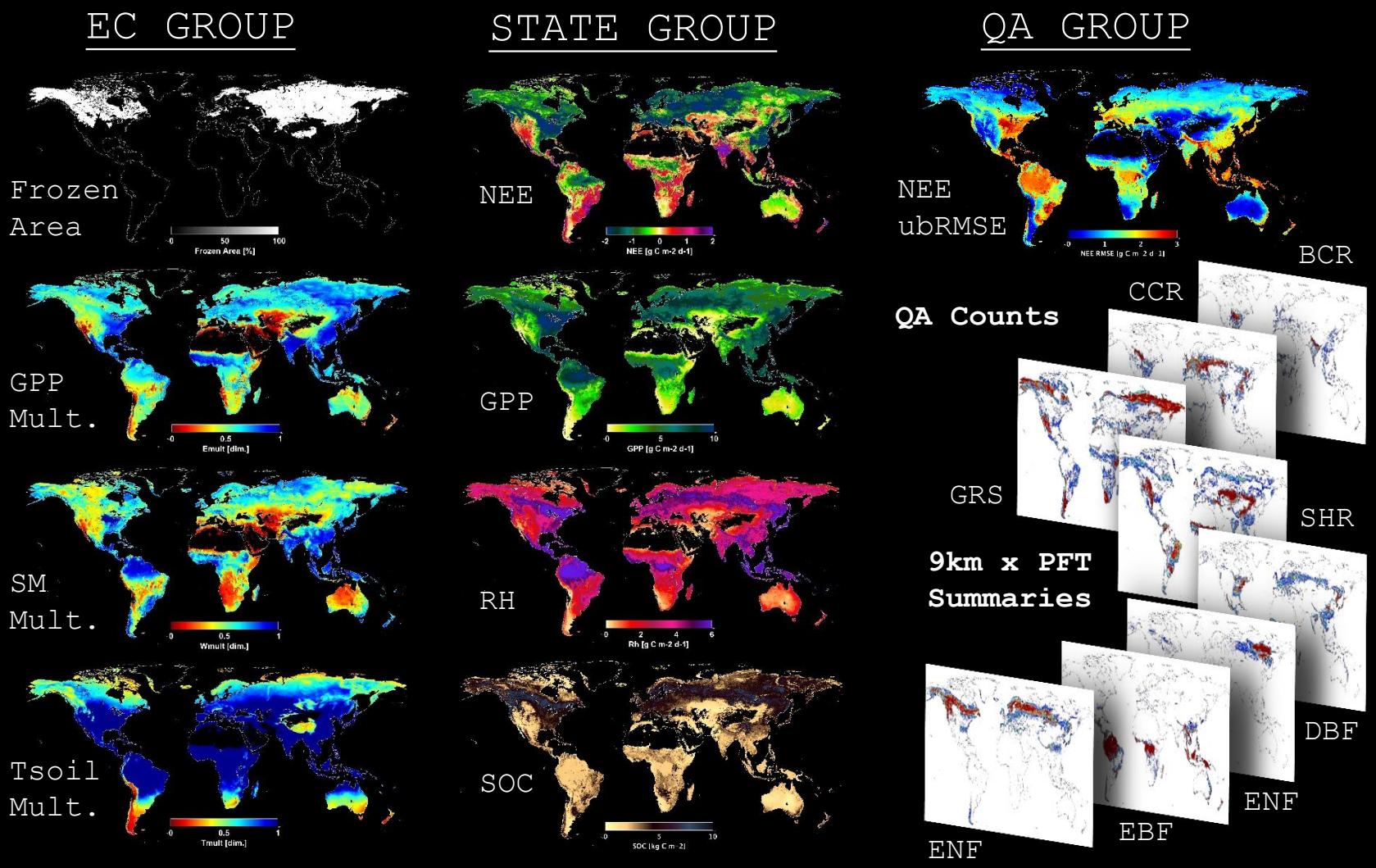
- L-band Radiometer (Passive, 1.41 GHz) and Radar (Active, 1.26 GHz)
- Radiometer 39 km x 47 km
- Radar 1-3 km footprint
- 6 meter antennae
- Global coverage every 3 days, twice daily > 50° N/S latitude, 6am/6pm

SMAP Level 4 Carbon (L4C) Model in a Nutshell

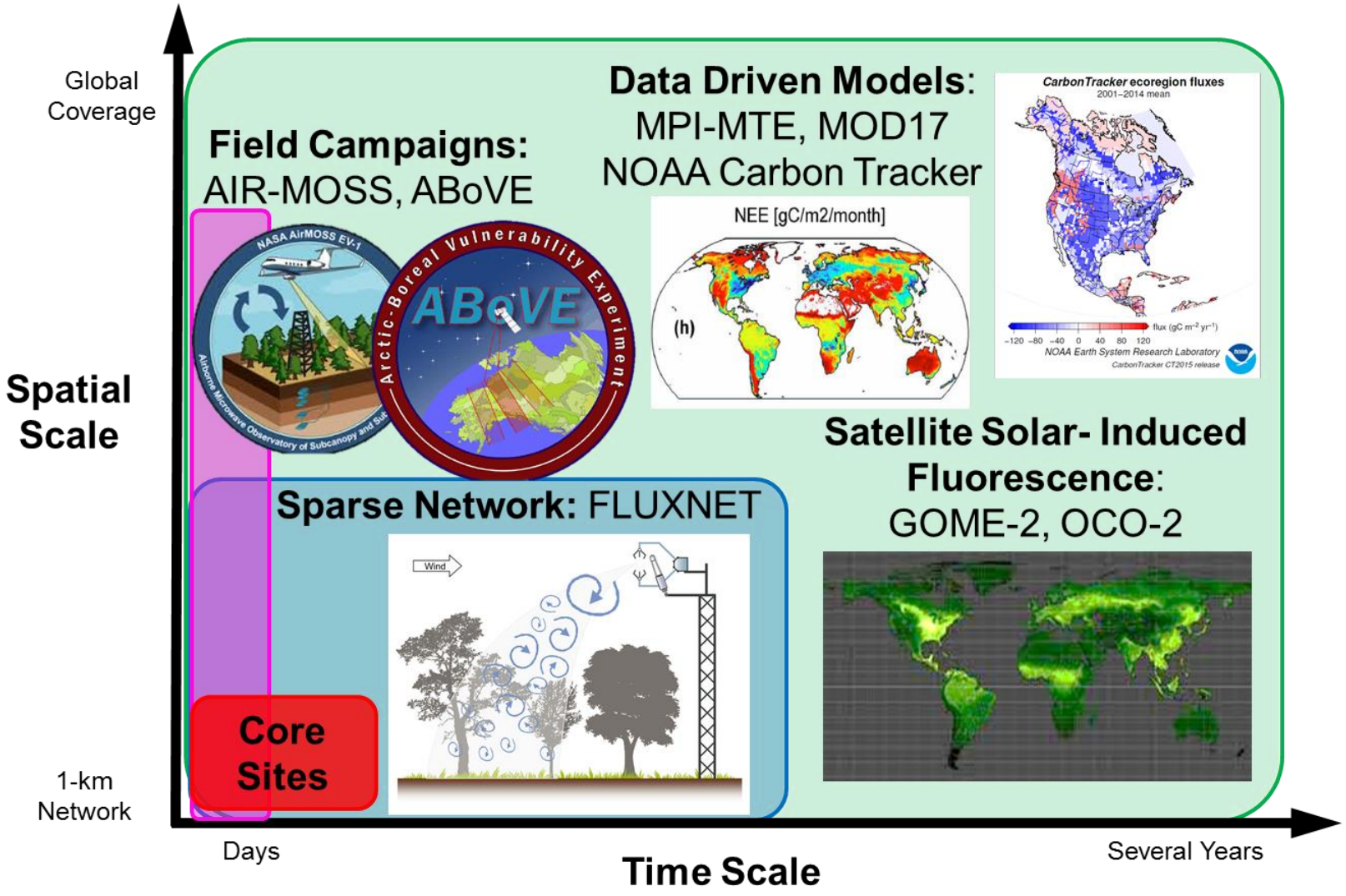


- Global daily 1-km processing, posted to 9-km Equal Area Scalable Earth (EASEv2) grid summarized by Plant Functional Type (PFT).

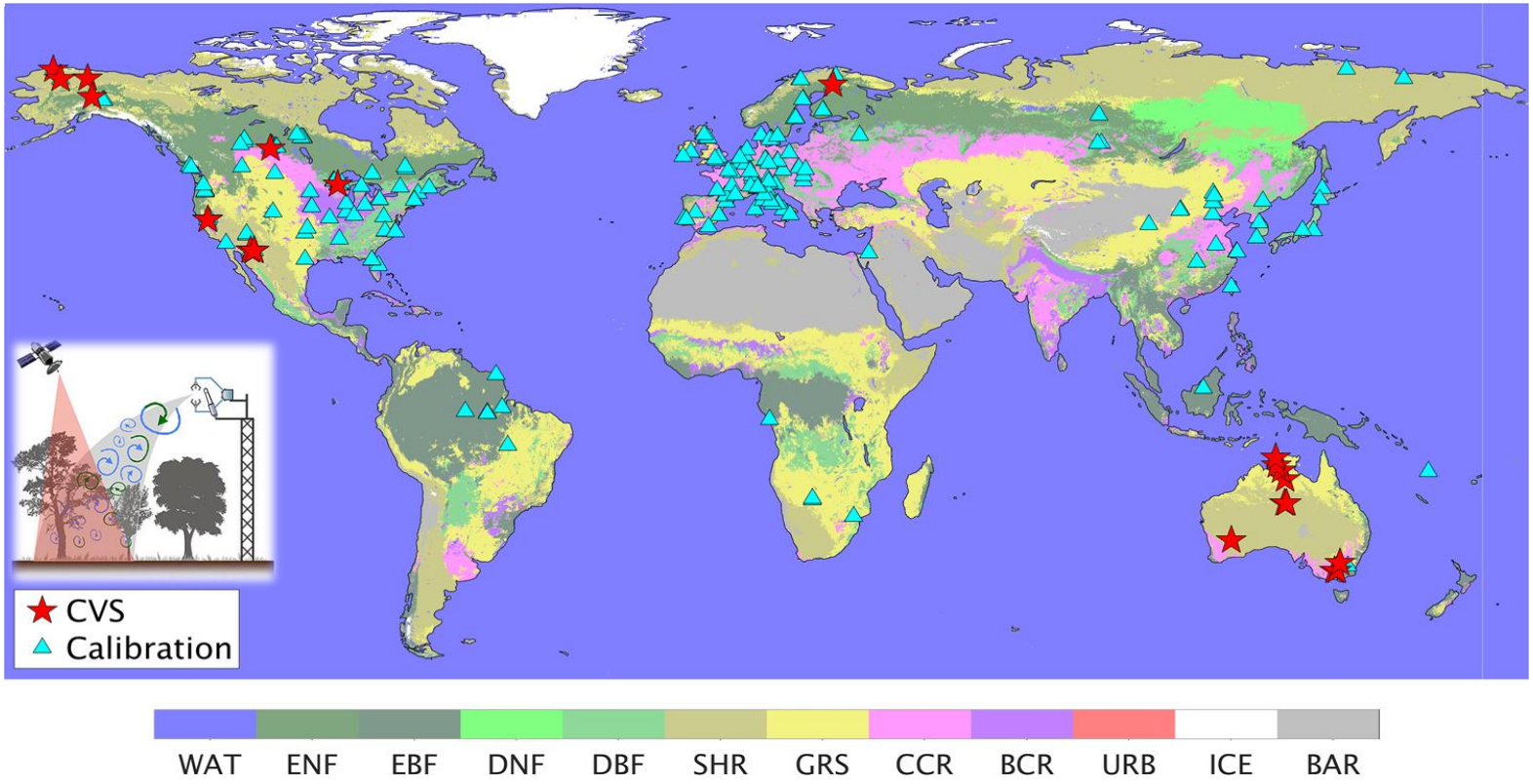
L4C Data Products



Multi-tier Validation

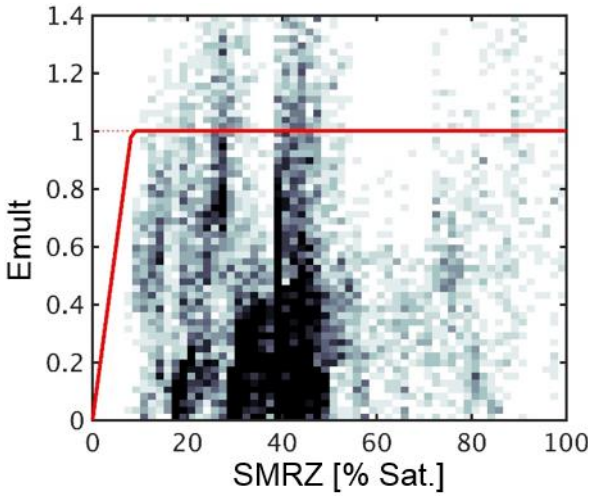


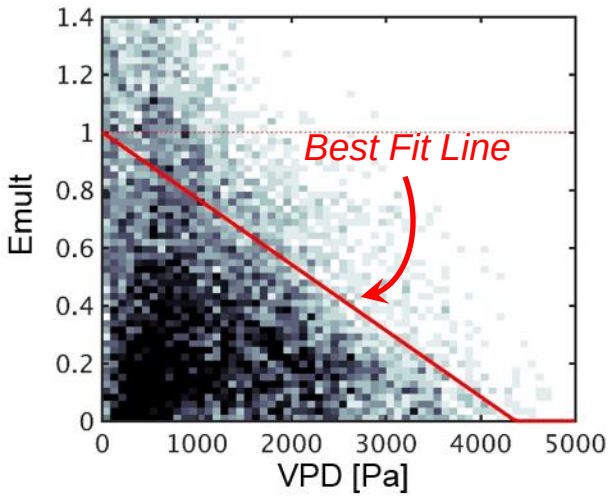
Flux Tower Calibration & Validation Network

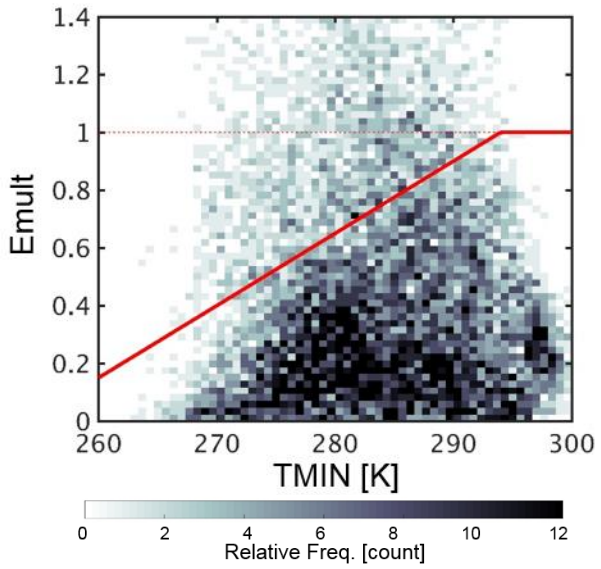


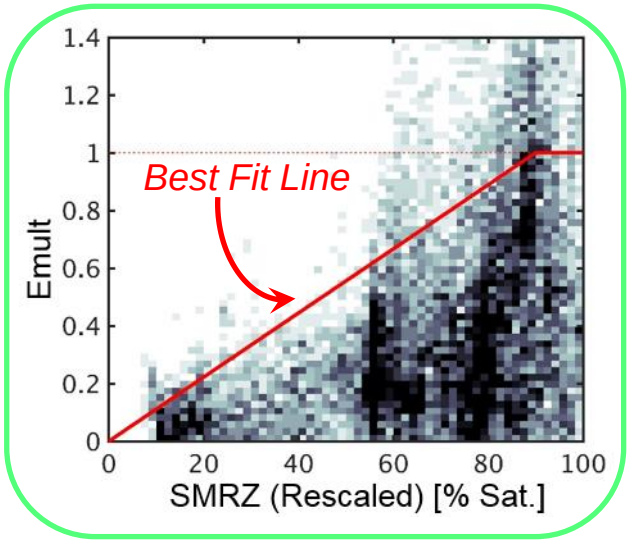
- **Core Validation Sites (CVS)**: 26 locations, 21 unique grid cells, provide recent flux tower data for SMAP mission period (March 31, 2015-present).
- **Calibration Sites**: 228 locations, FLUXNET La Thuile Database, historic fluxes for SMAP Nature Run period (2001-2007).

GPP Calibration (Shrubland Example)

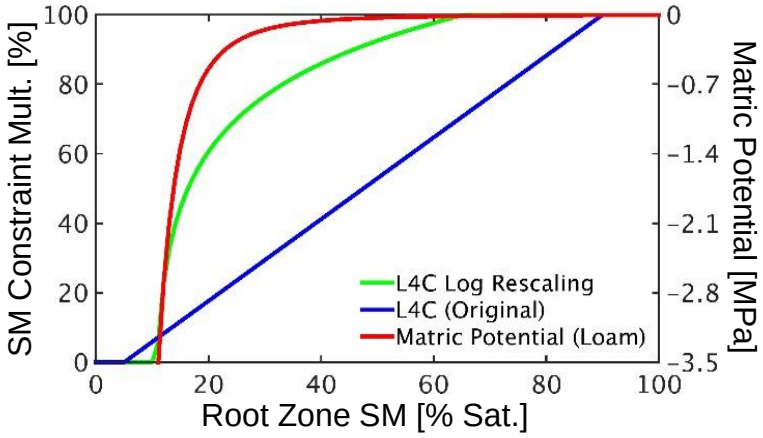






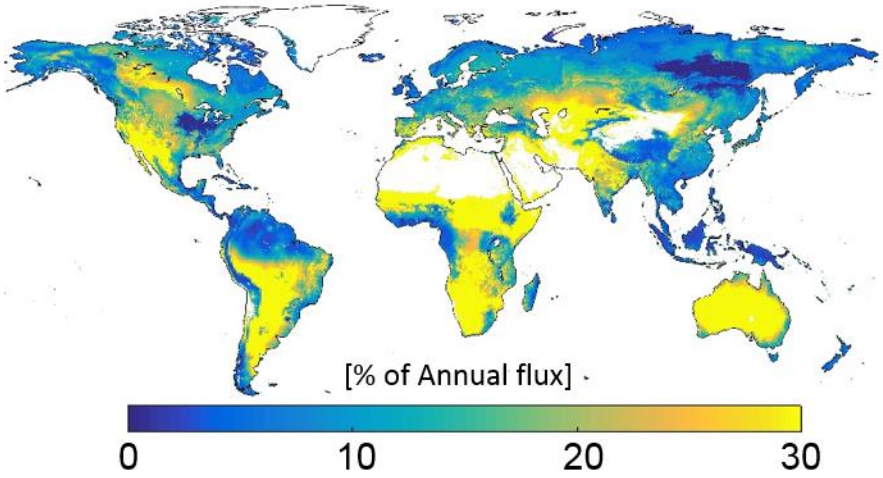


$$Emult = \frac{GPP}{\varepsilon_{\max} * APAR}$$

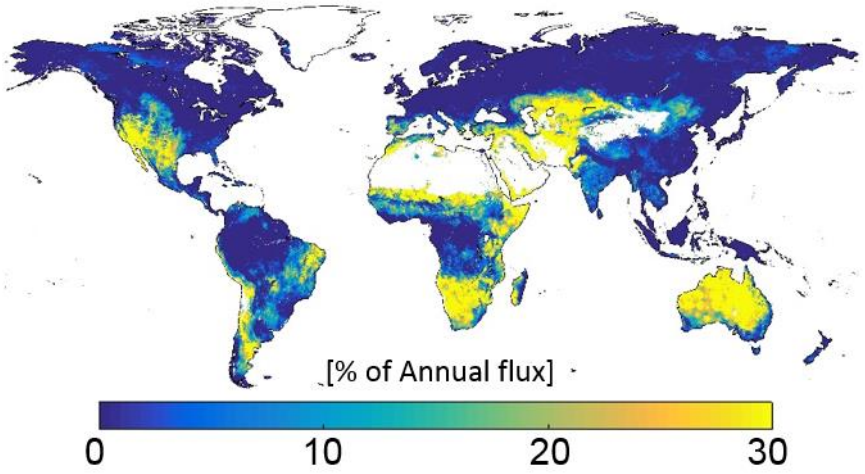


Soil Moisture Constraint Exclusion Experiment

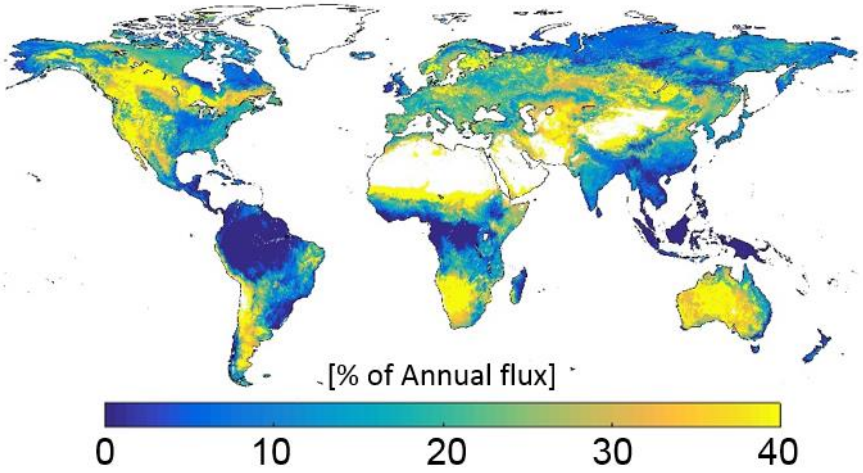
Vapor Pressure Deficit ⟶ GPP



Root Zone Soil Moisture ⟶ GPP



Surface Soil Moisture ⟶ Soil Resp.



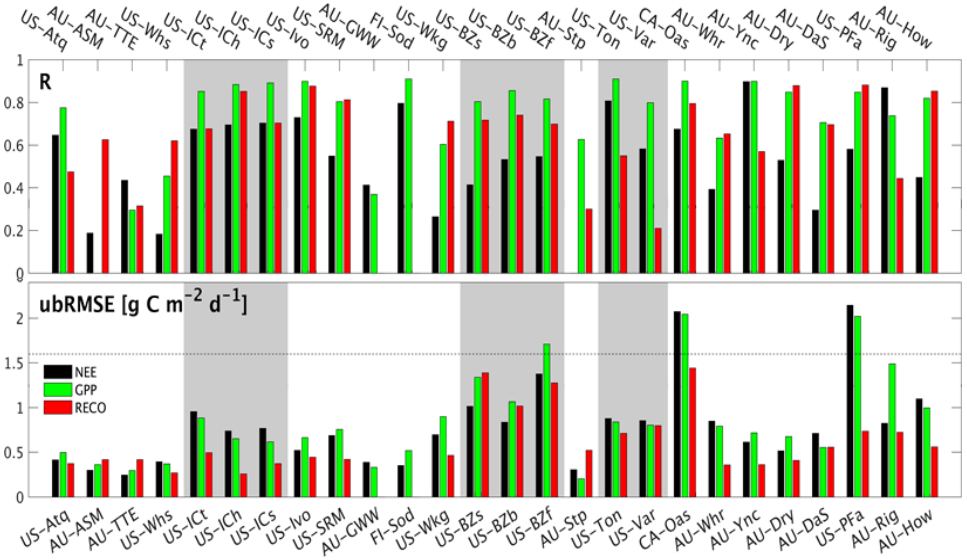
- Soil moisture affects GPP in arid shrub/grass regions.
- VPD influence extends to most forests.
- Soil moisture has a widespread impact on soil respiration.

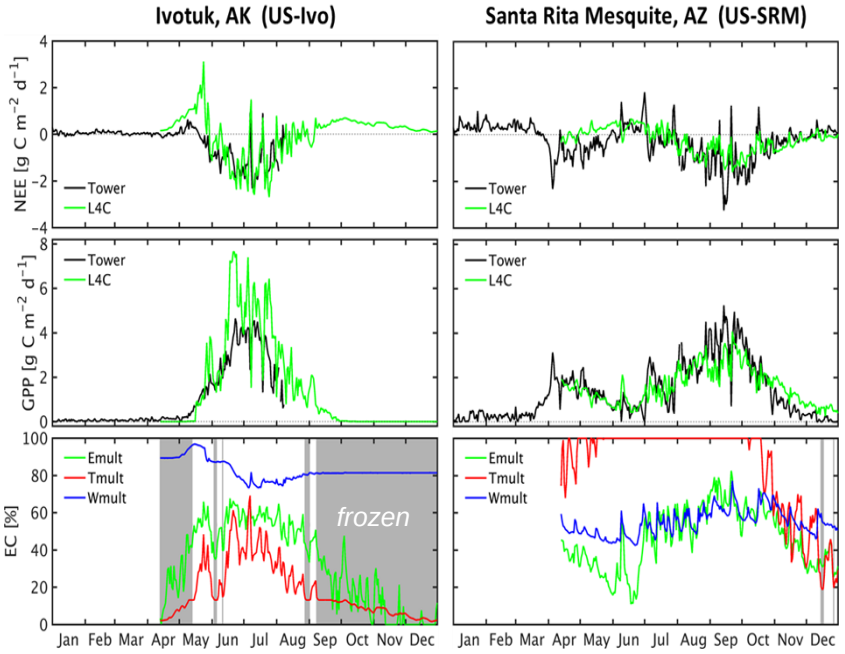
Flux Tower Validation Results

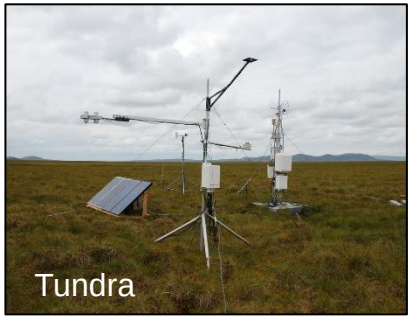
Overall:

NEE [g C m^{-2} d^{-1}]				GPP [g C m^{-2} d^{-1}]				R_{eco} [g C m^{-2} d^{-1}]			
R	RMSE	ubRMSE	N	R	RMSE	ubRMSE	N	R	RMSE	ubRMSE	N
0.52	1.04	0.79	26	0.72	1.27	0.85	26	0.65	1.16	0.62	24

Individual Sites:



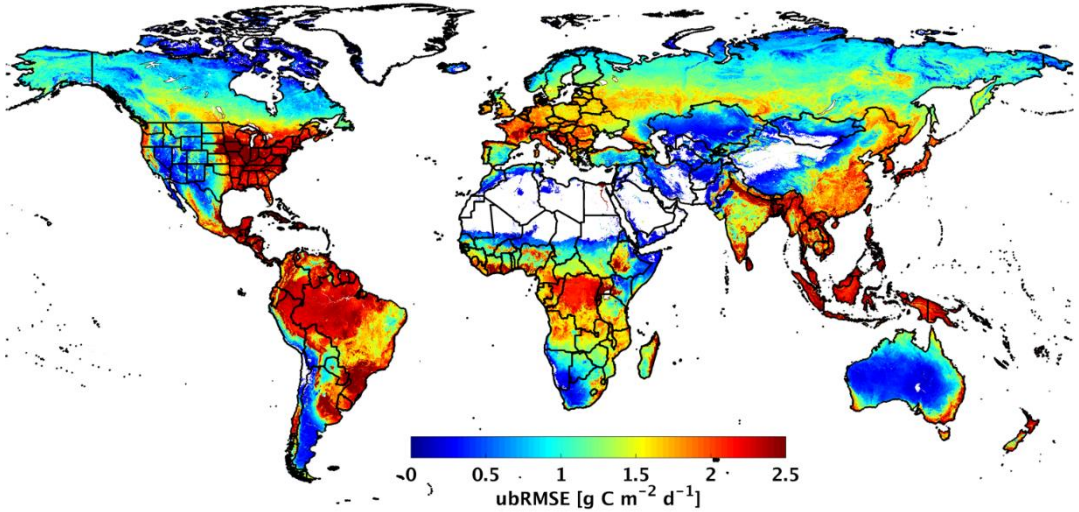


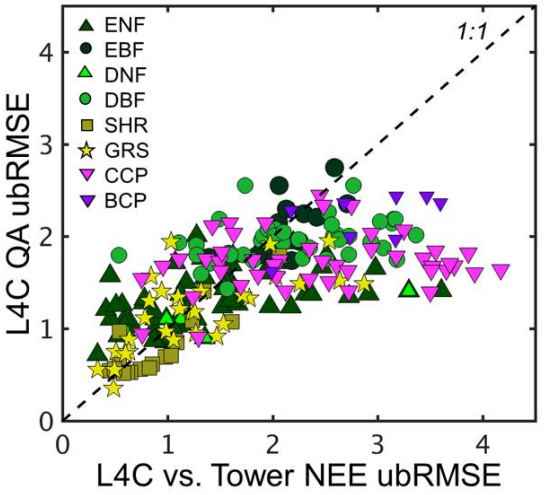


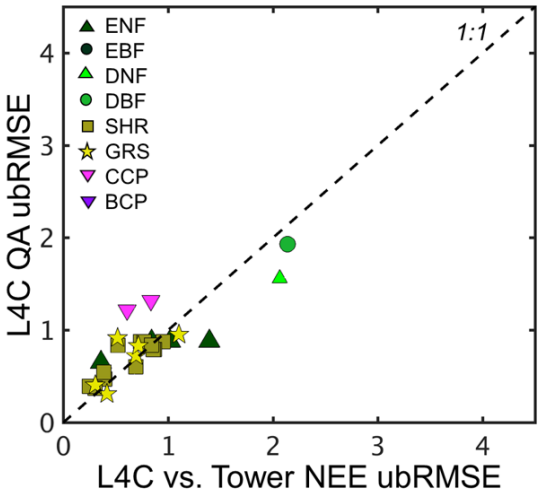
Desert, Tundra — Increasing Flux $|GPP + RECO|$ — *Forest, Savanna*

Uncertainty Estimates & Quality Assessment

Estimated Daily Average NEE RMSE [g C m^{-2} d^{-1}]





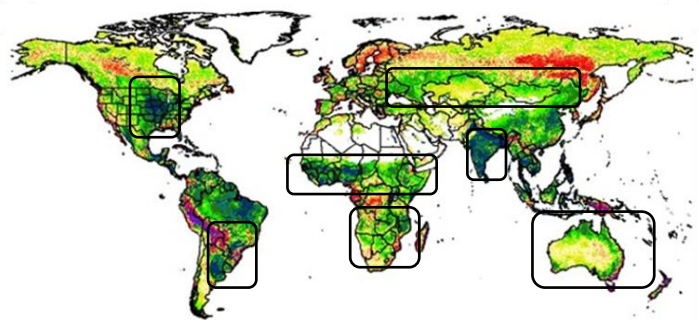


- Error propagated using input error and L4C model derivatives.
- Scales proportionally with annual flux and biomass.
- Fit plateaus for RMSE>1.5 g C m^{-2} d^{-1} (Cropland & Forest).

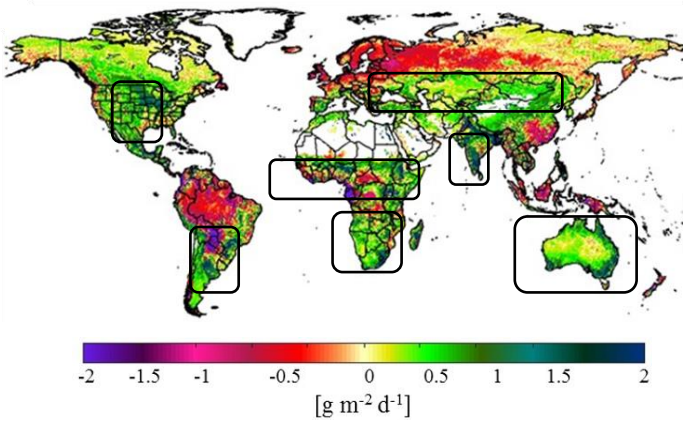
GPP Comparison with MOD17 & GOME-2 SIF

L4C Increases Seasonal Cycle Amplitude

L4C minus MOD17



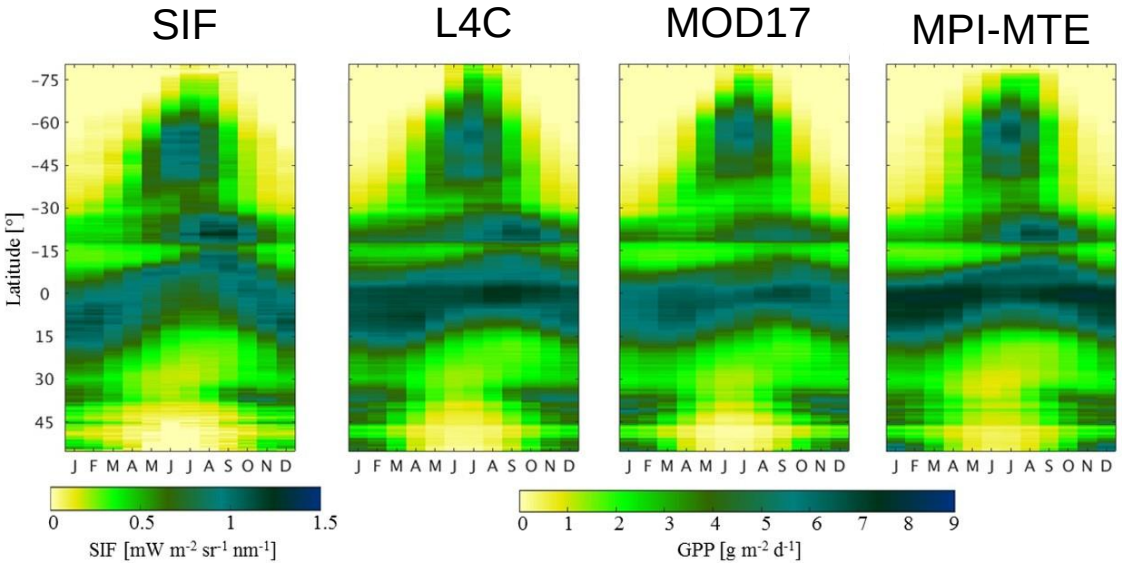
L4C minus MPI-MTE



Monthly Correlation Summary for CVS Flux Towers.

	Site	SIF	L4C
SIF	0.63		
L4C	0.85	0.73	
MOD17	0.81	0.63	0.85

Mean Seasonal Cycle by Latitude



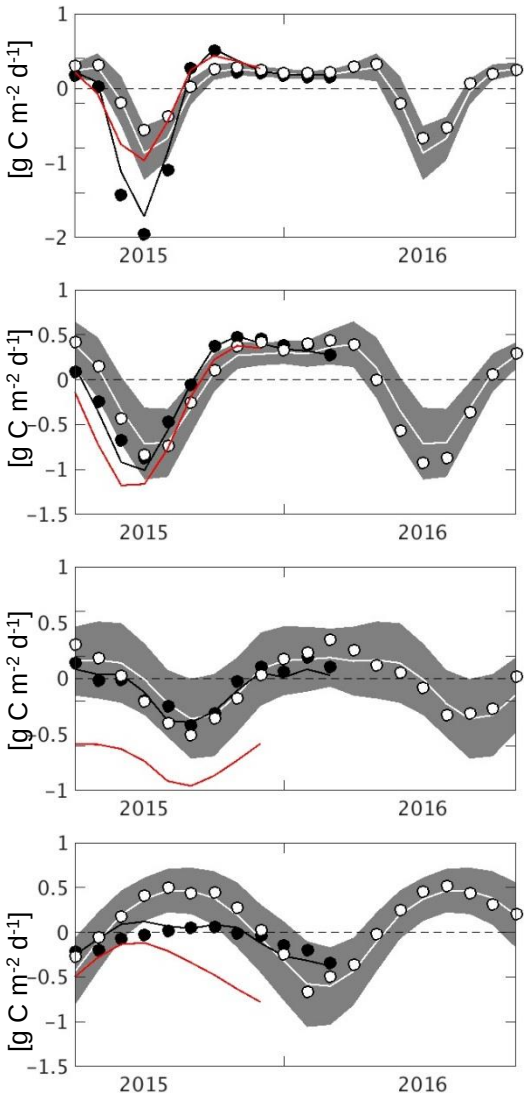
NEE Comparison with CarbonTracker & MPI-MTE

Boreal

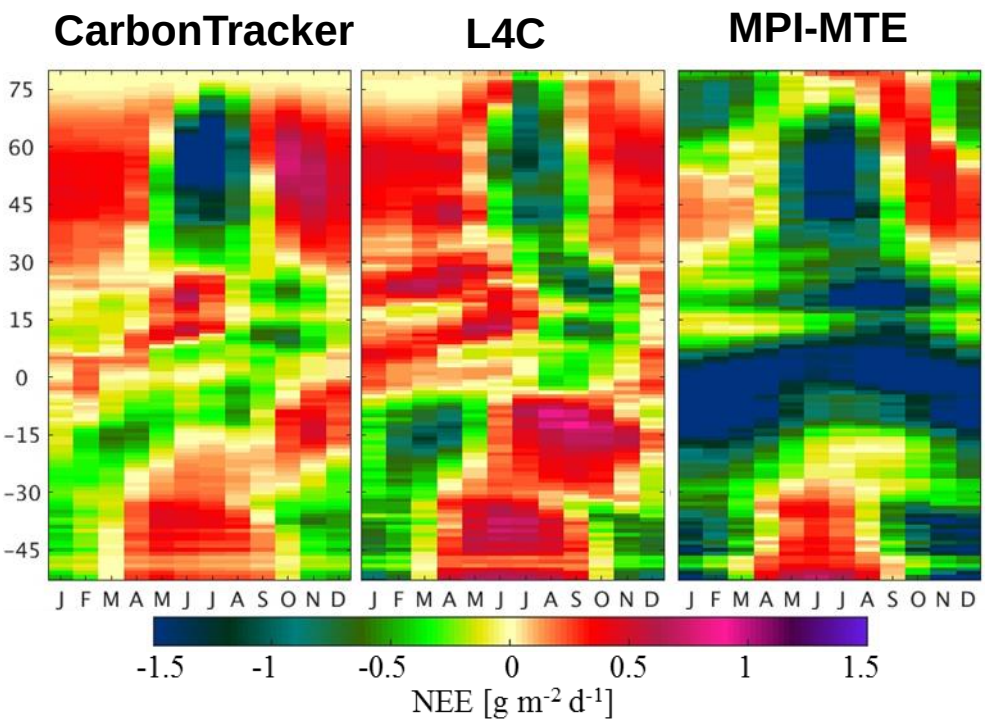
Northern Temperate

Tropical

Southern Temperate

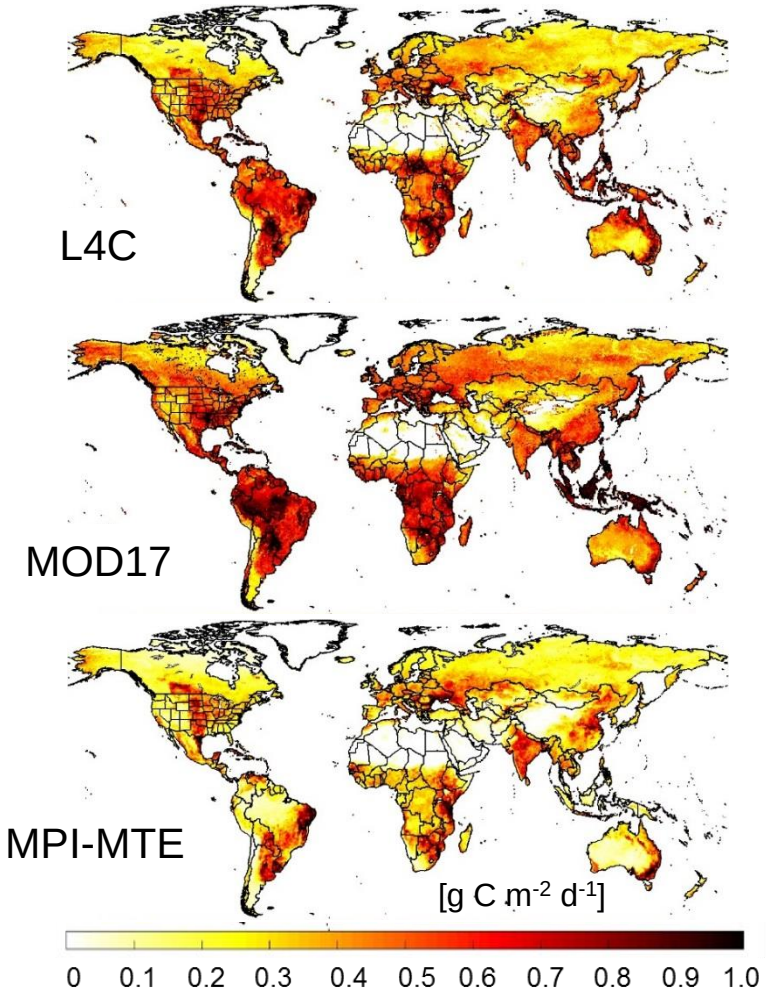


Carbon Tracker Climatology
L4C Climatology (±1 Anom. Stdev.)
MPI-MTE Climatology
Carbon Tracker 2015
L4C 2015-2016



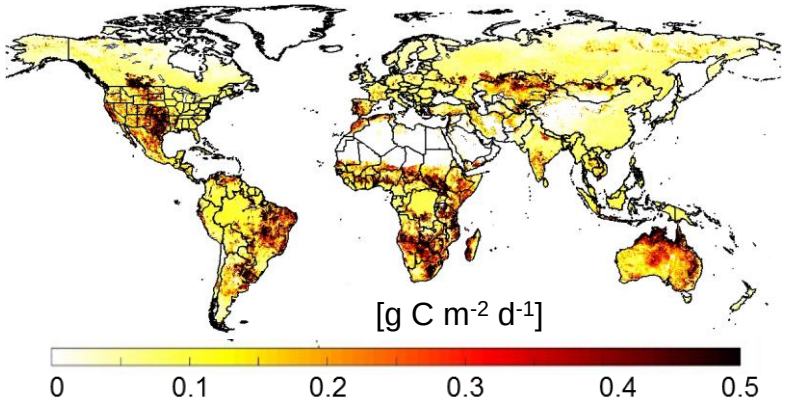
SMAP Influences L4C in Semi-Arid Regions

Daily GPP Anomaly Stdev.



Impact of SMAP Obs on L4C GPP

(L4C using L4SM vs. NatureRun RMS Difference)

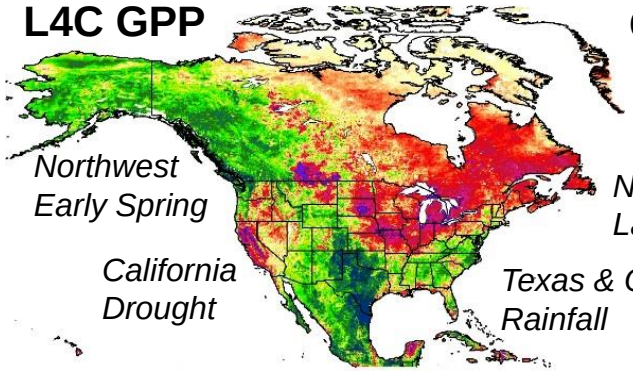


- L4C regions of largest inter-annual anomaly variance generally align with SMAP impact.
- Suggests potential for SMAP to inform interannual variability.
- More SMAP influence in China following upcoming L4SM version release.

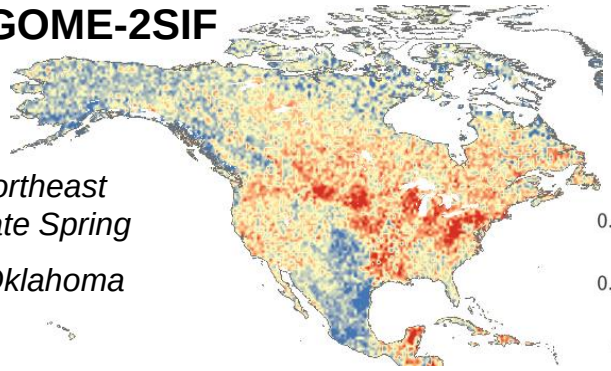
North America Anomalies (2015 & 2016)

May & June 2015 Anomaly

L4C GPP

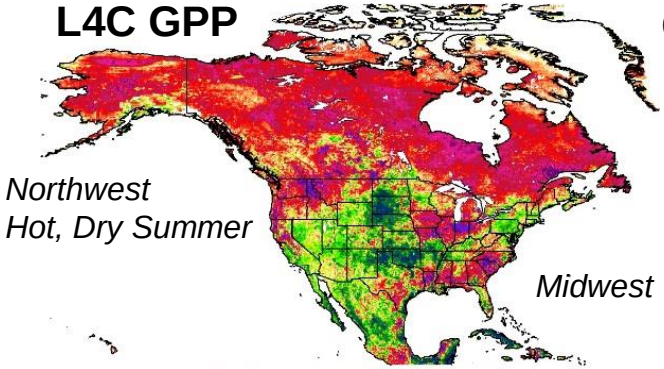


GOME-2SIF

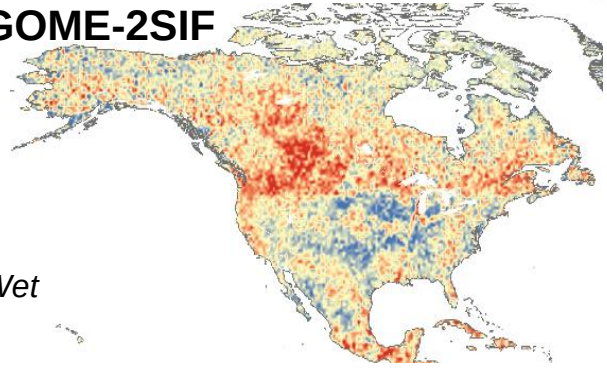


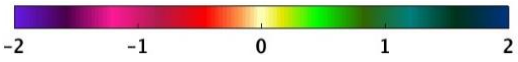
July & August 2015 Anomaly

L4C GPP



GOME-2SIF

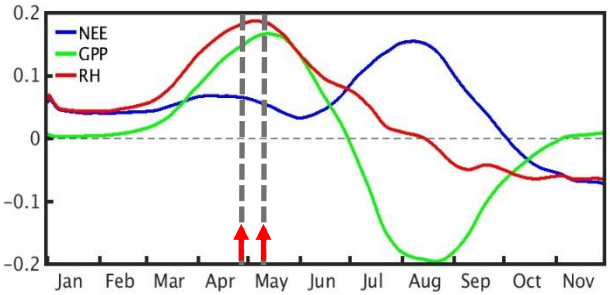




[g C m^{-2} d^{-1}]

[mW m^{-2} sr^{-1} nm^{-1}]

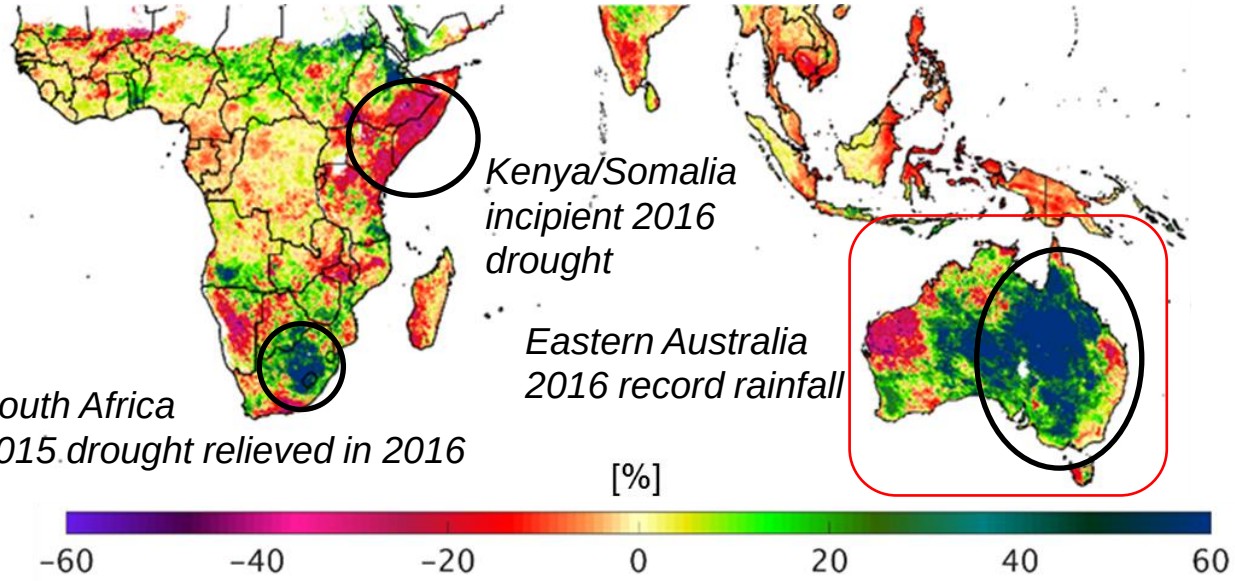
NASA ABoVE Region L4C Seasonal Flux Anomaly (2016)



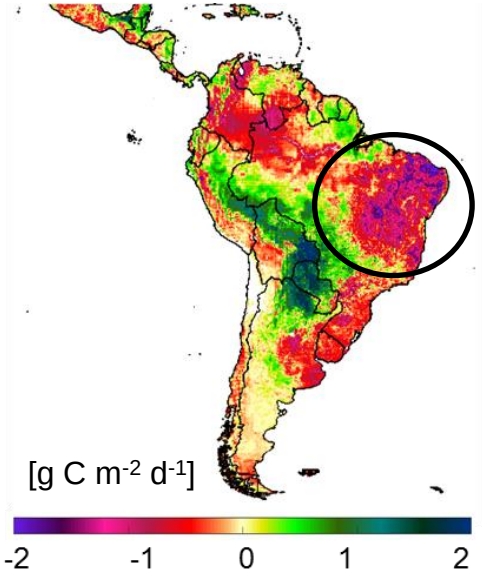
Typical Thaw: May 10
2016 Thaw : April 29 (11 days early)

Southern Hemisphere Anomalies (2015 & 2016)

L4C GPP change (%) from 2015 to 2016 (April-Dec.)



L4C GPP anomaly 2016 (April-Dec.)

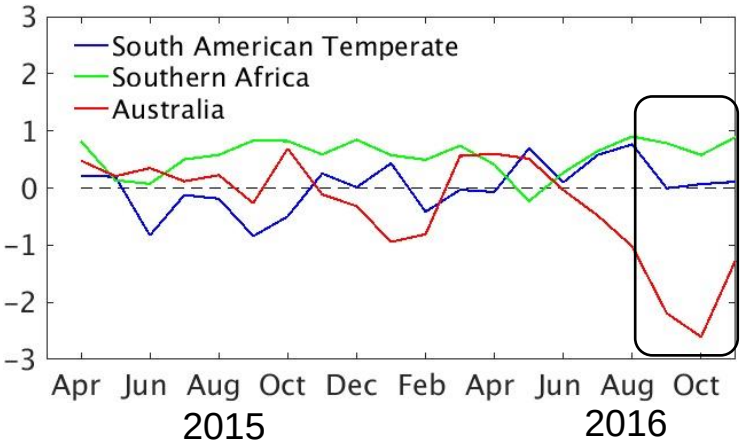


Brazil drought 2015-2016

- L4C anomalies respond to extreme conditions (drought and rainfall) highlighted in recent news headlines.
- Following slides focus on Australia …

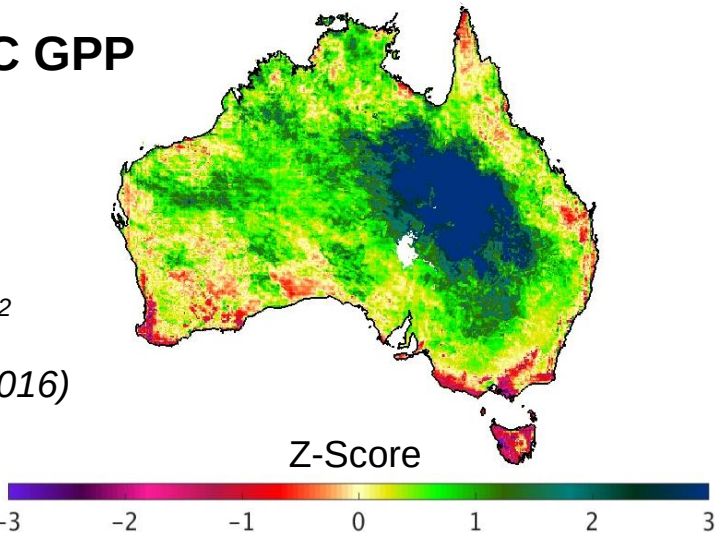
Australia Rainfall Anomaly (Sep. – Nov. 2016)

L4C NEE Monthly Z-Score

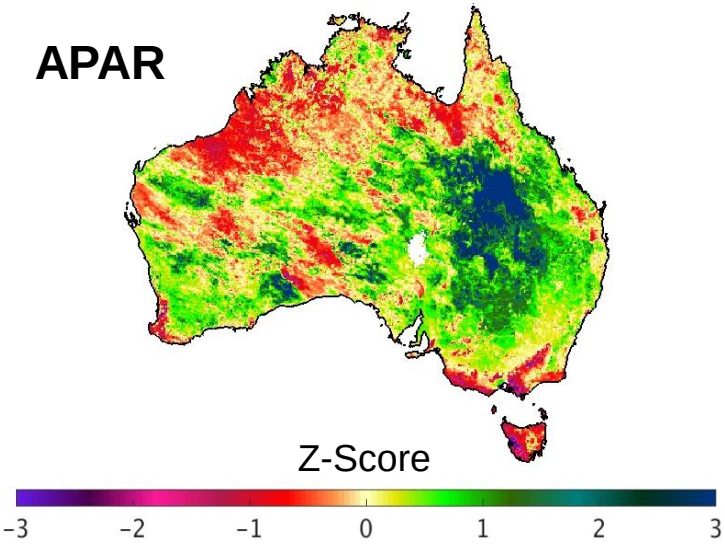


Increased CO_2 Uptake (Sept – Nov 2016)

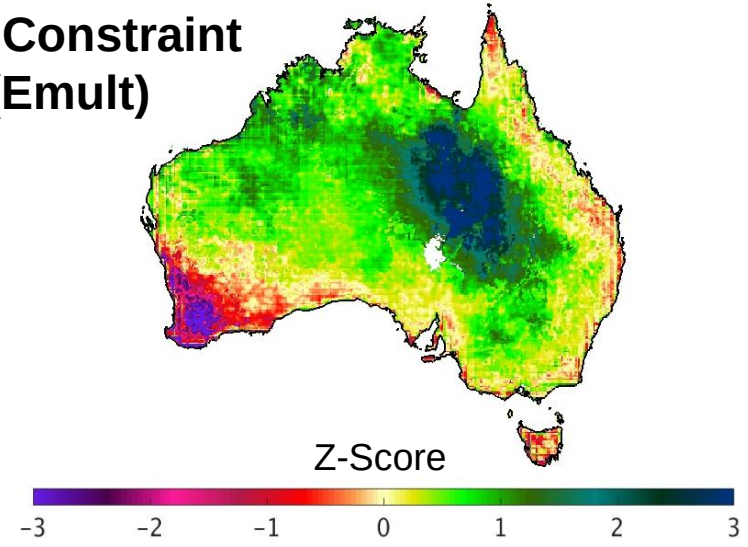
L4C GPP



APAR

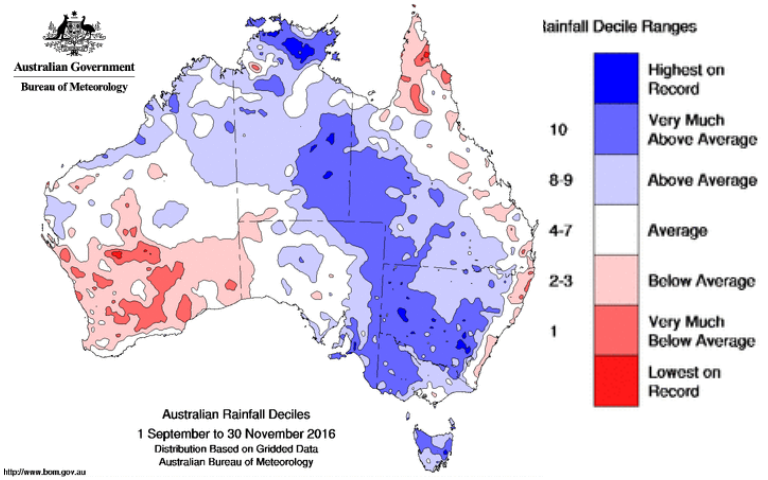


LUE Constraint (Emult)

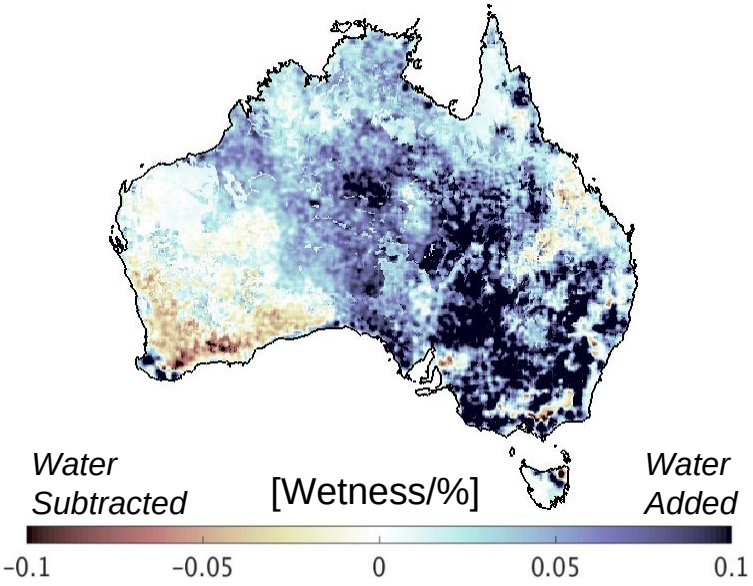


Australia L4SM Perspective

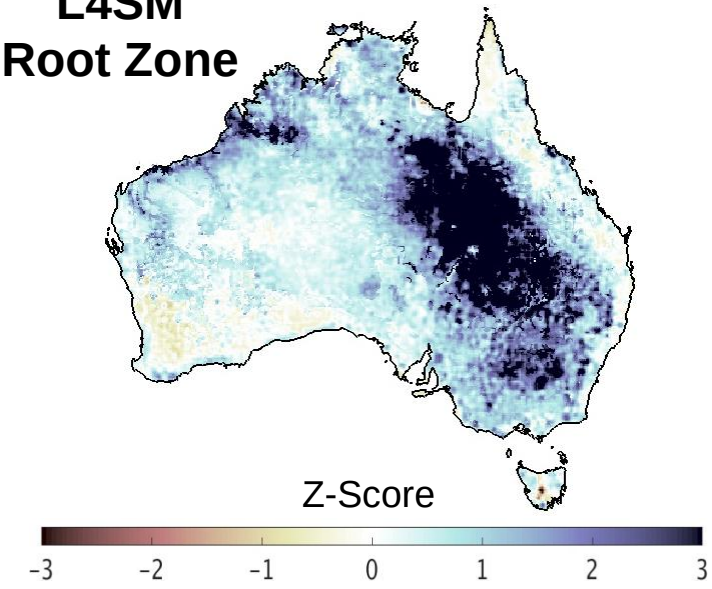
- L4C anomaly driven by increased greenness and relaxed soil moisture constraint.
- SMAP observations added water to L4SM root zone analysis strengthening the wet anomaly.



SMAP SM Contribution

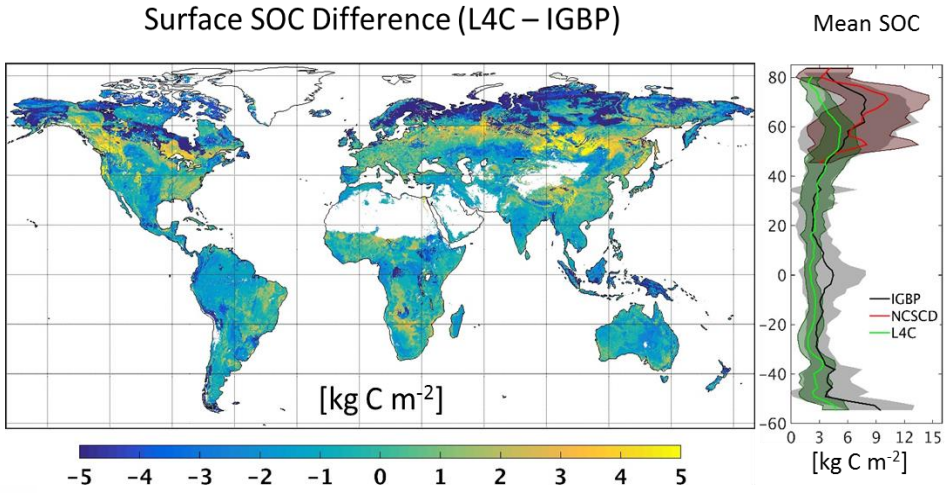


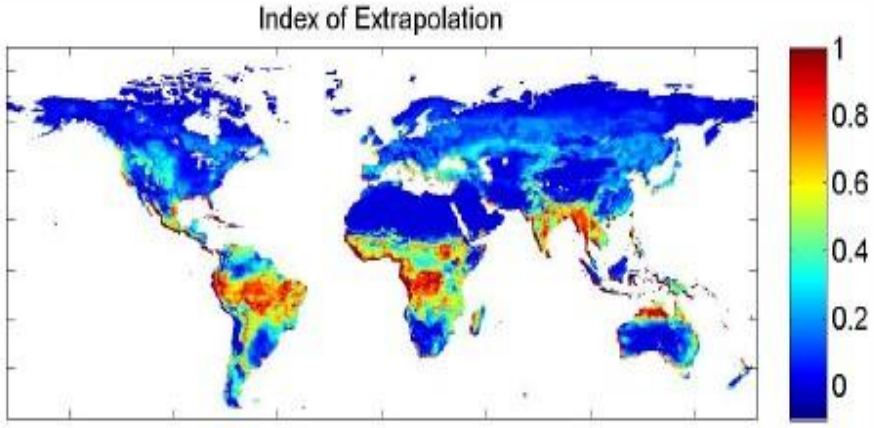
L4SM Root Zone

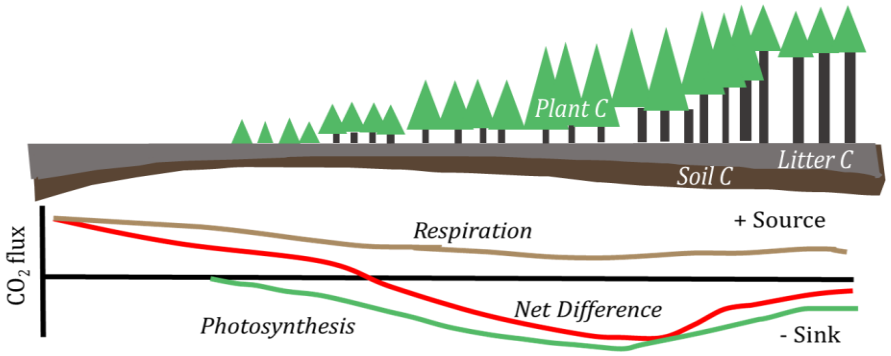


L4C Caveats

- NEE source/sink results depends on SOC initialization.
- Soil moisture and other input data have biases.
- Representation error.
- Extrapolation error.
- Model structure and optimization.





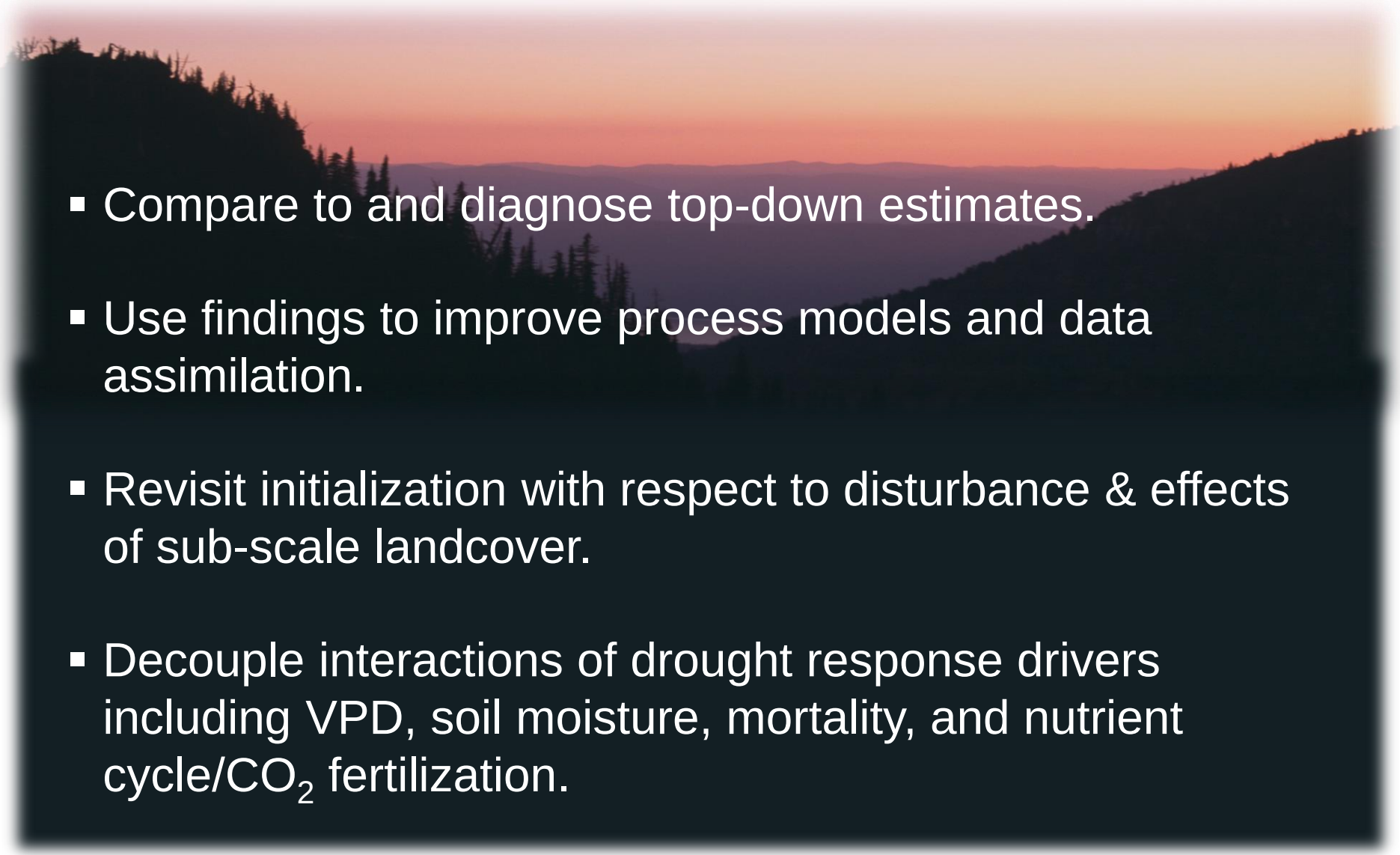


From M. Jung et al. 2009. *Biogeosci*. 6, 2001-13.

Summary & Conclusion

- L4C dataset available at NSIDC (updates for MODIS Collection 6 to be released mid-April): http://nsidc.org/data/SPL4CMDL
- L4C Provides a new moisture-constraint perspective relative to other global datasets.
- SMAP soil moisture incremental information content is highest in arid and semi-arid regions.
- These regions coincide where soil moisture controls L4C NEE variability.
- SMAP value not yet clearly quantifiable – longer time series required.

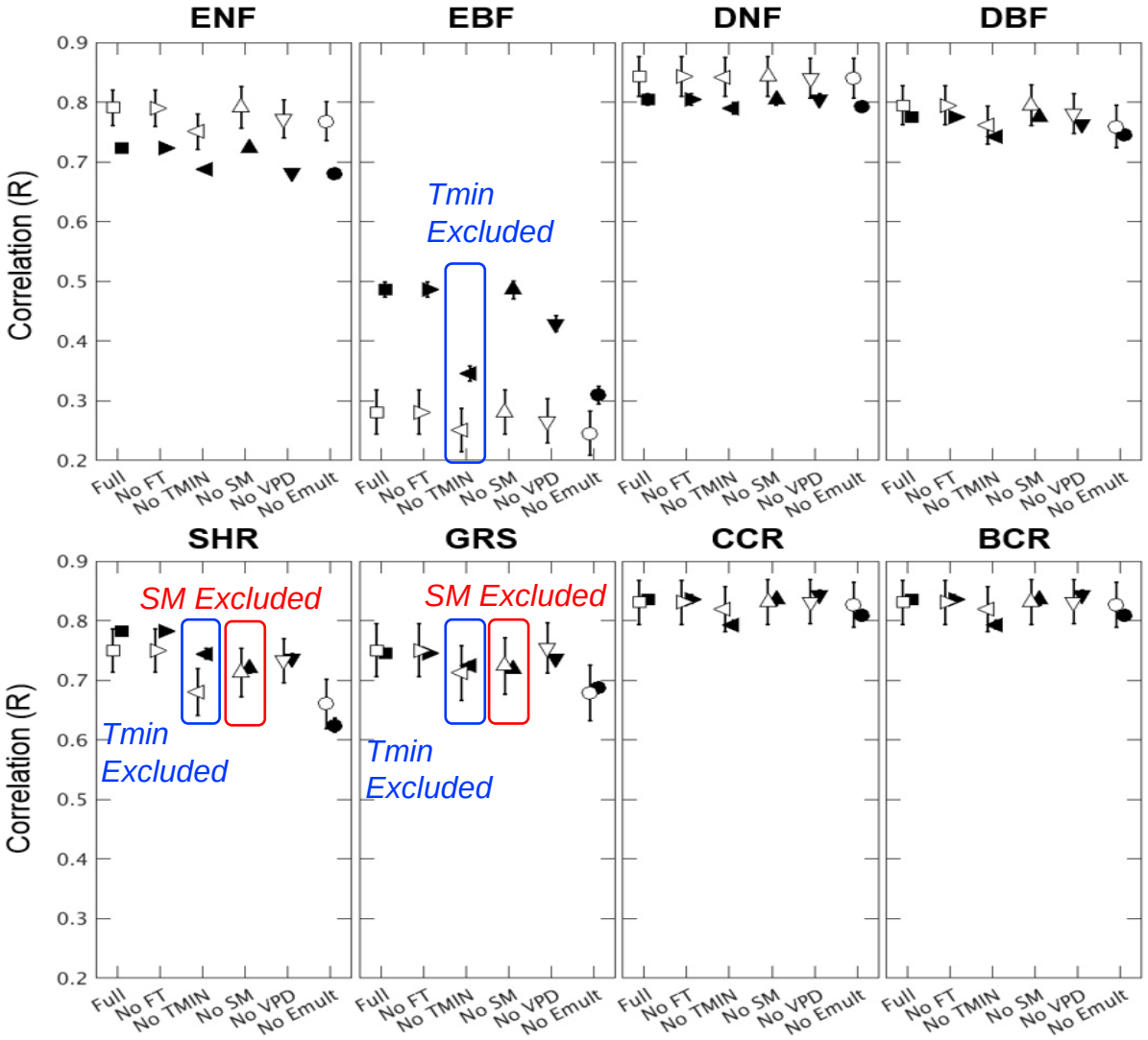
Focus Points Looking Forward



- Compare to and diagnose top-down estimates.
- Use findings to improve process models and data assimilation.
- Revisit initialization with respect to disturbance & effects of sub-scale landcover.
- Decouple interactions of drought response drivers including VPD, soil moisture, mortality, and nutrient cycle/CO_2 fertilization.

Extra Slides

GPP Constraint Exclusion Experiment By Landcover



Pooled Correlation
(Closed Symbols)

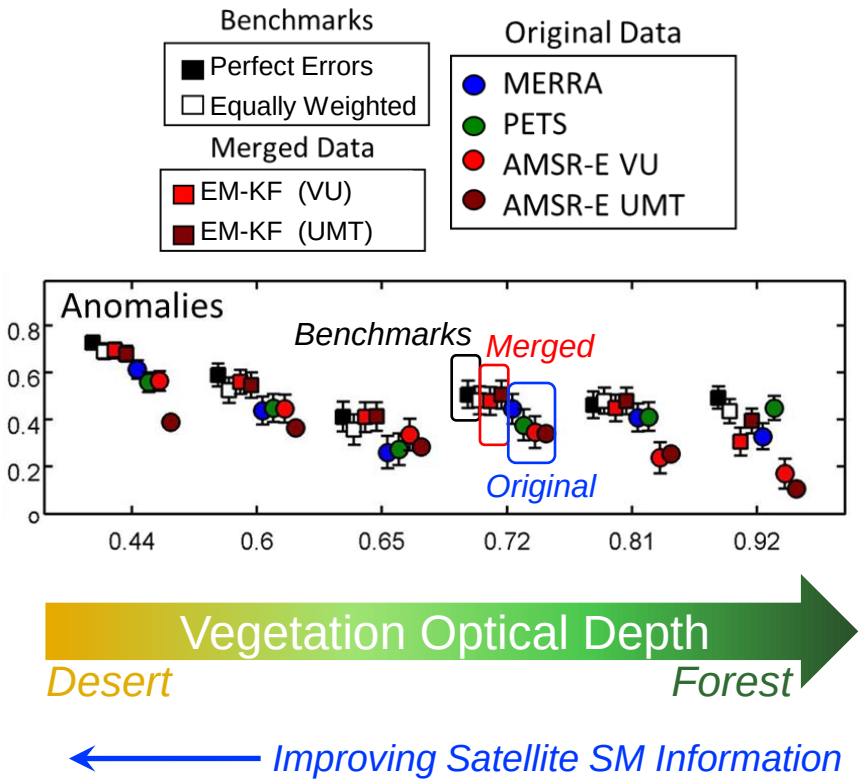
- Includes spatial patterns/biases.
- Closely aligned with fitting procedure cost function.

Average Correlation
(Open Symbols)

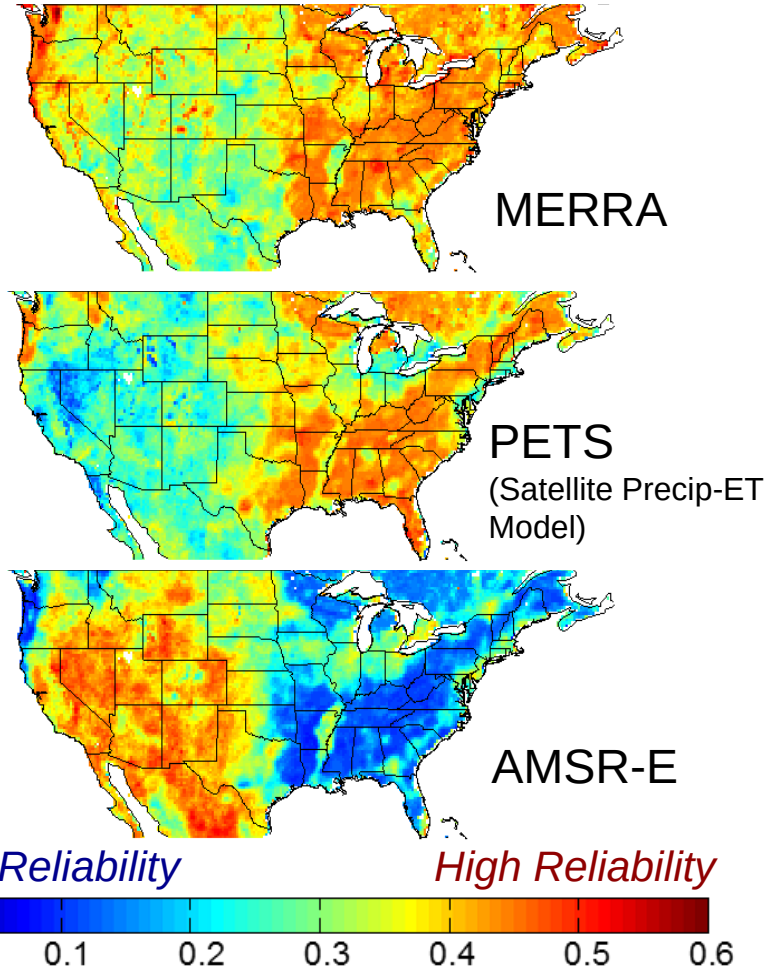
- No spatial information
- Typical values for an individual site

Merging Soil Moisture Datasets (Pre-SMAP)

Correlation vs. In Situ Soil Moisture



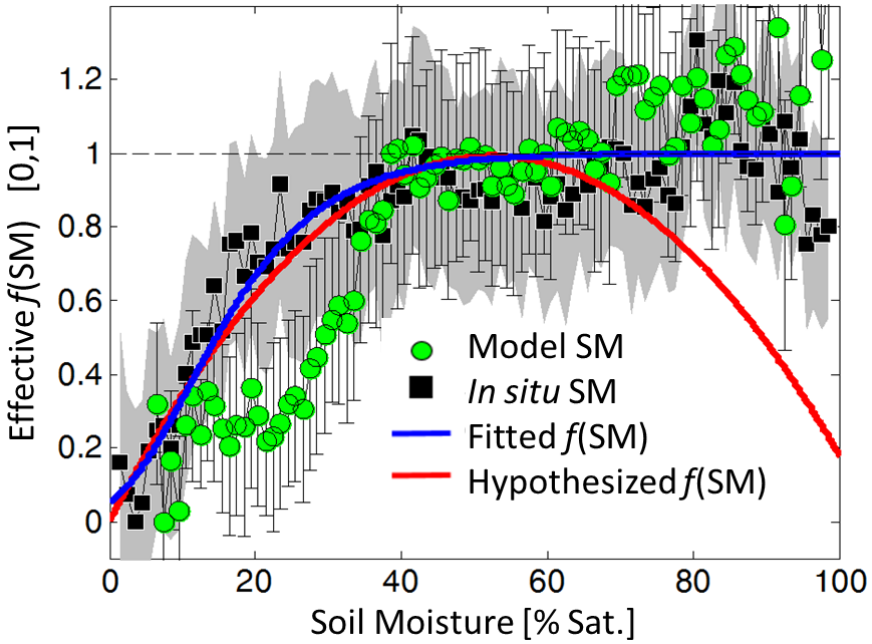
Merging Weights [0,1]

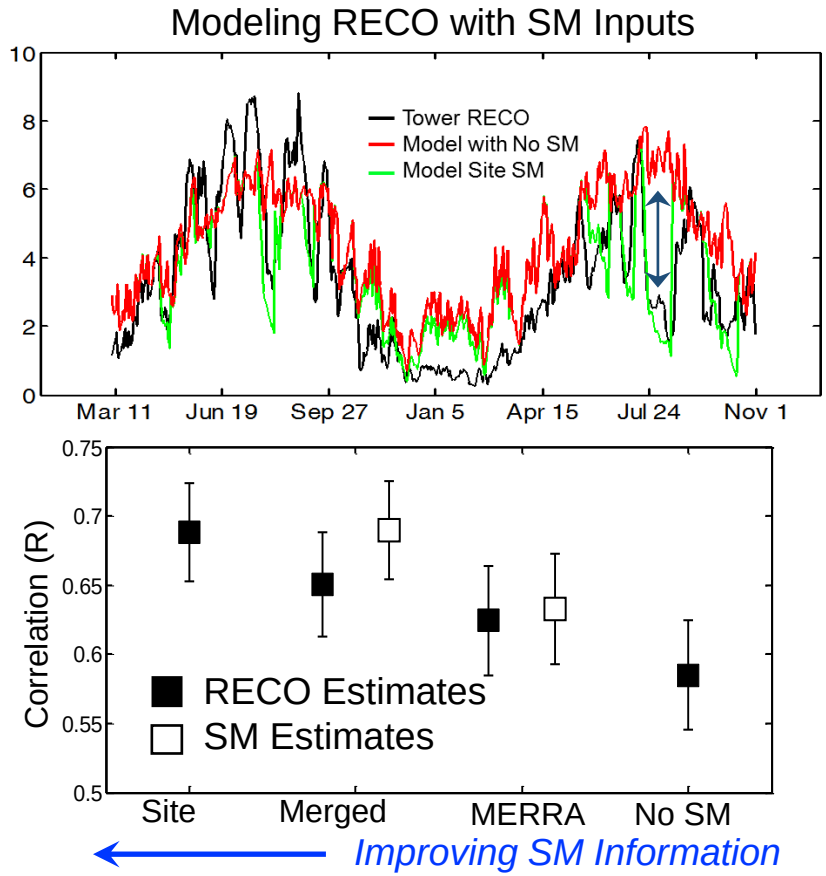


Estimating Ecosystem and Soil Heterotrophic Respiration (Pre-SMAP)

Autotrophic *Heterotrophic* Normalizing Term

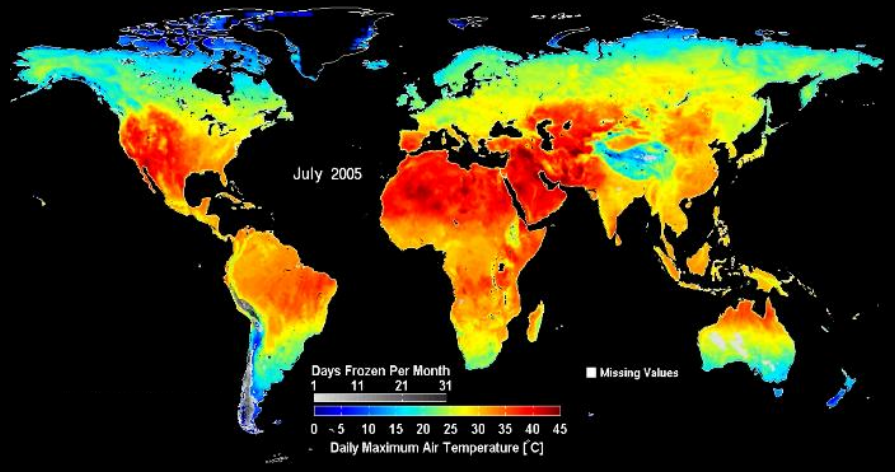
$$RECO = f_{aut} GPP + f(TSOIL)\, f(\mathrm{SM})\, k_{\max} \mathrm{SOC}$$



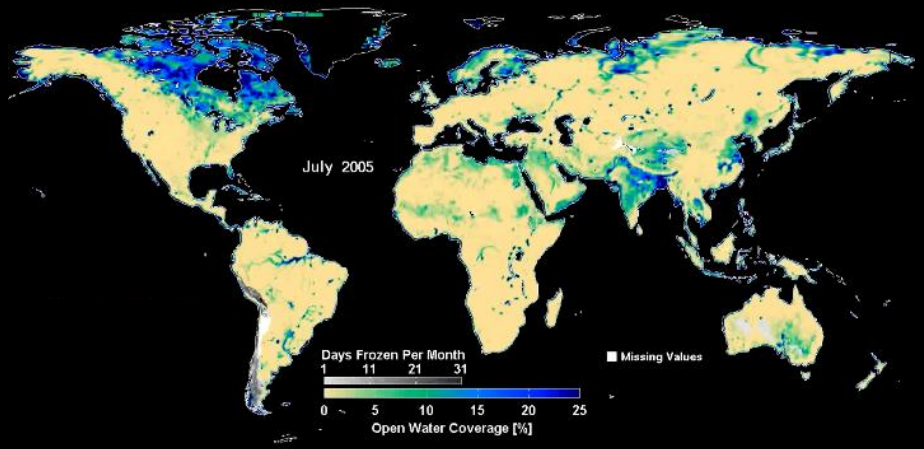


Monitoring the Biosphere with Microwave Land Observations

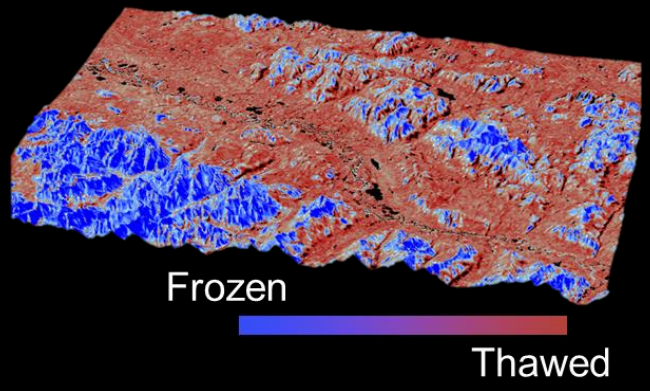
Soil, Surface, and Air Temperatures



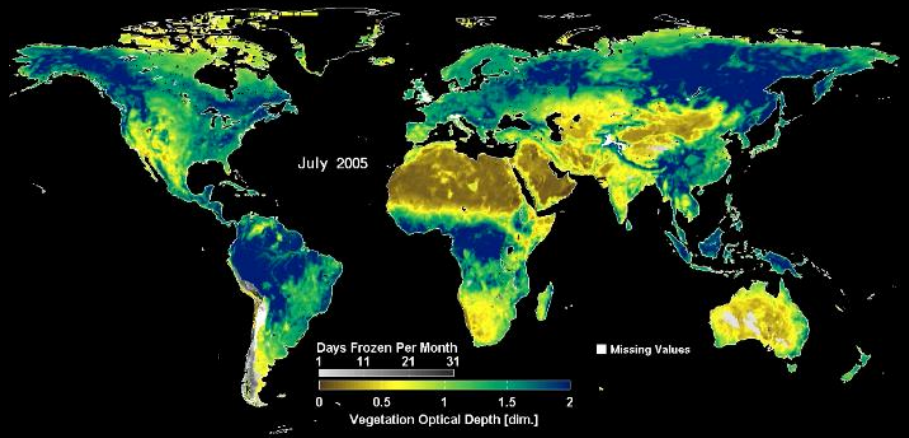
Open Water Fractional Coverage



Freeze-Thaw State (non-binary)

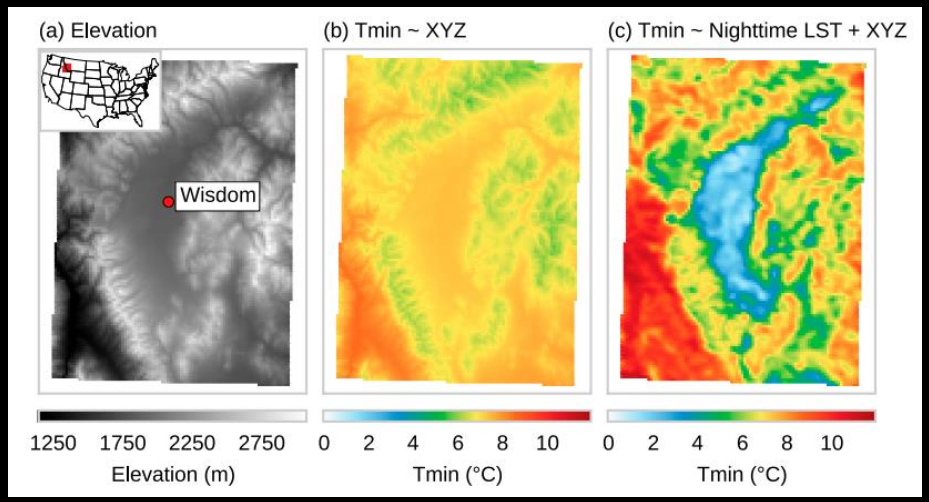


Vegetation Optical Depth



Fine-Scale Surface Meteorology from MODIS

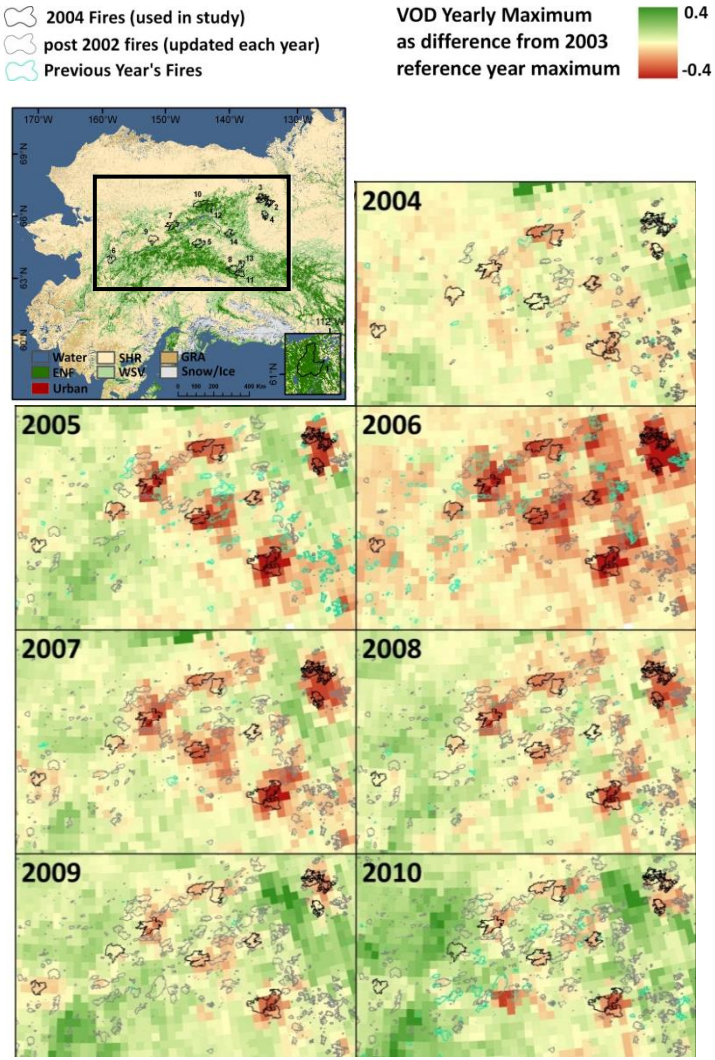
High Elevation Big Hole Valley, MT



Oyler, J.W., S.Z. Dobrowski, Z.A. Holden, and S.W. Running (2016), Remotely sensed land skin temperature as a spatial predictor of air temperature across the conterminous United States. *J. Appl. Meteorol. Climatol.*, http://dx.doi.org/10.1175/JAMC-D-15-0276.1.

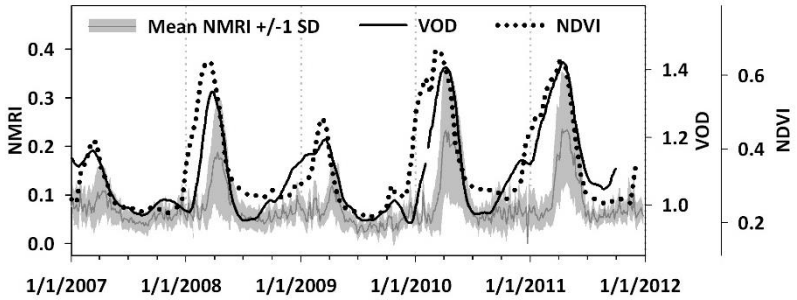
- MODIS LST climatology was a significant unique predictor of station daily minimum temperature.
- Potential for improving LUE model estimates.
- Used in TopoWx 1-km daily meteorology dataset for CONUS: https://github.com/jaredwo/topowx

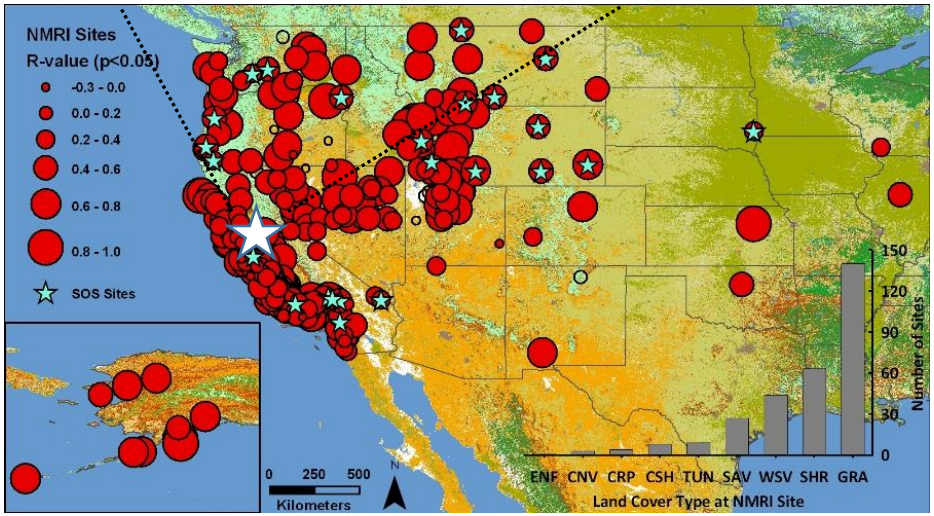
A Closer Look at Vegetation Optical Depth



Jones, M.O., et al. 2013 *Global Change Biology,* 19:3111-22

- Tracks boreal forest fire recovery
- Validated with GPS ground station "Multi-path" retrievals

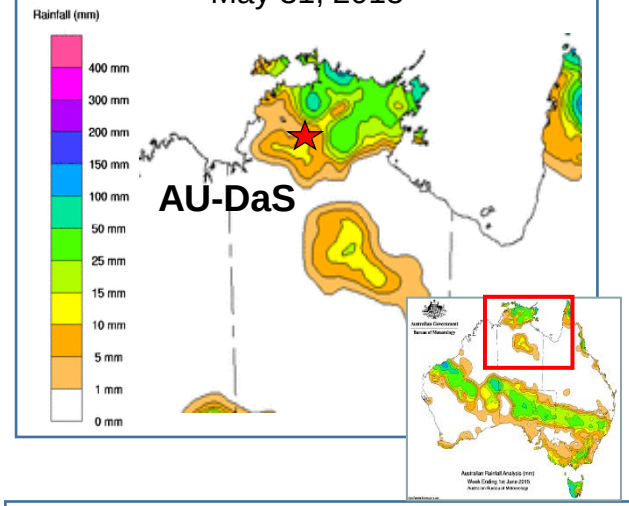


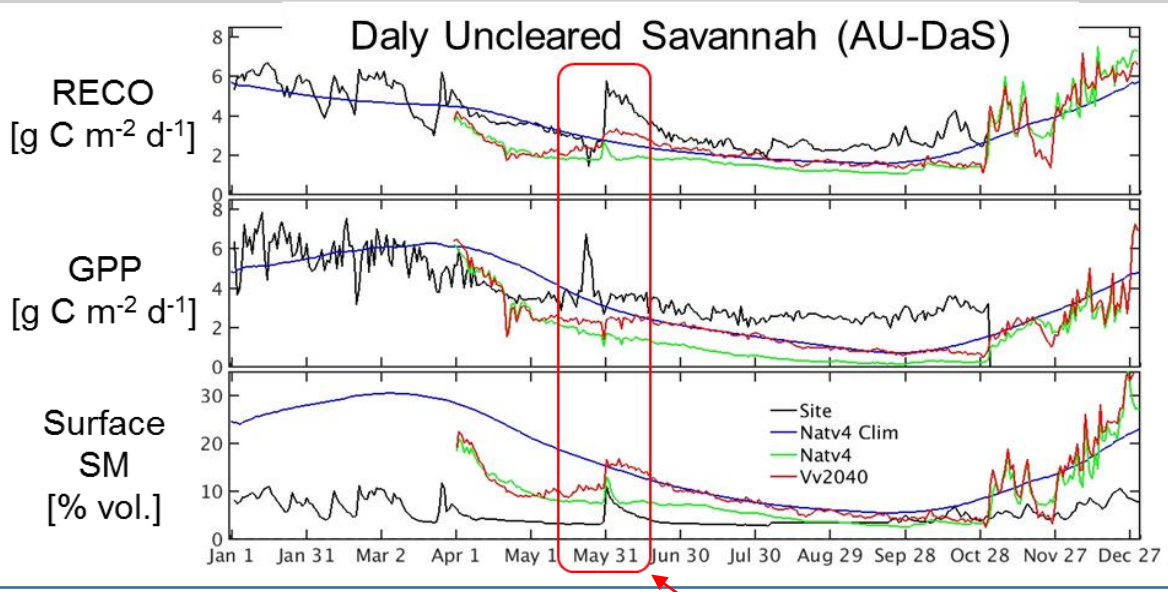


Jones, M.O., 2012, *Rem. Sens. Environ.* 123: 324-33.
Jones, M.O., 2014, Int. J. Biomet. 58: 13605-15.

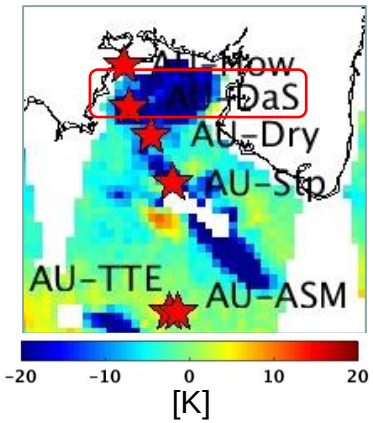
Tracking a Single Rain Event (Australia)

Australia Obs Precip for week ending May 31, 2015

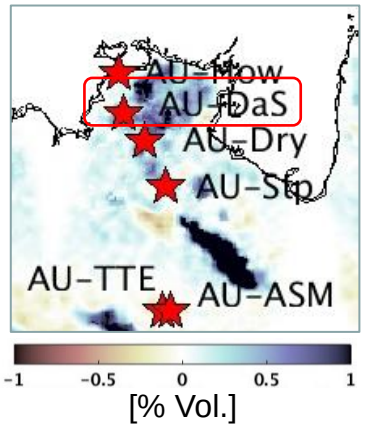




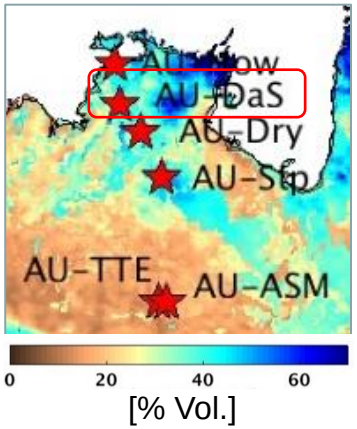
Model TbH - SMAP TbH
May 31



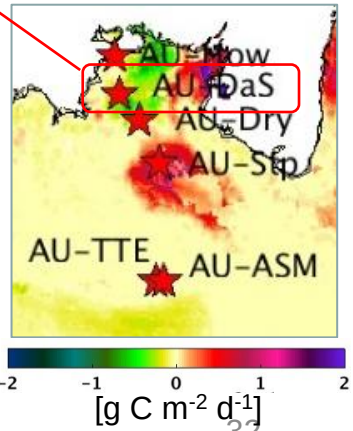
SM Analysis – SM Forecast
May 31



SM Analysis
May 31

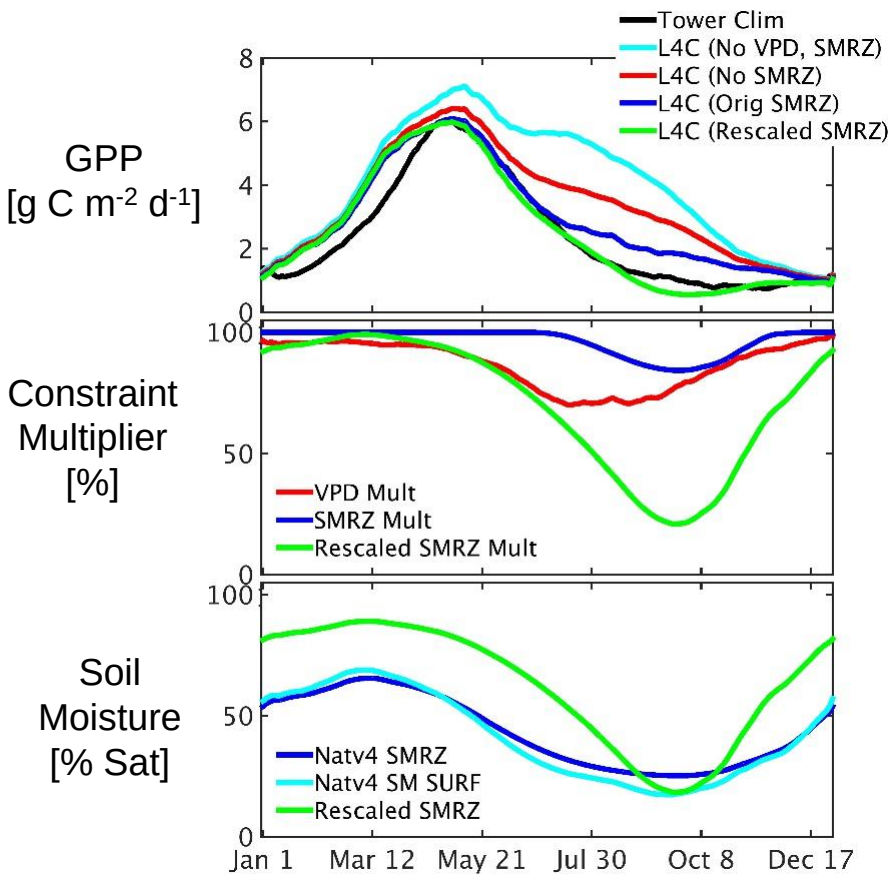


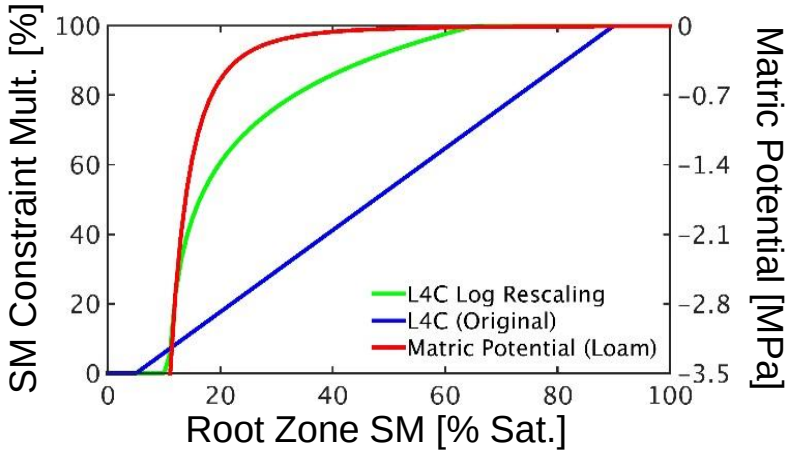
ΔRH
May 31-May 30



L4_C Root Zone SM Rescaling

Rescaling of root zone soil moisture improves L4C agreement with observations



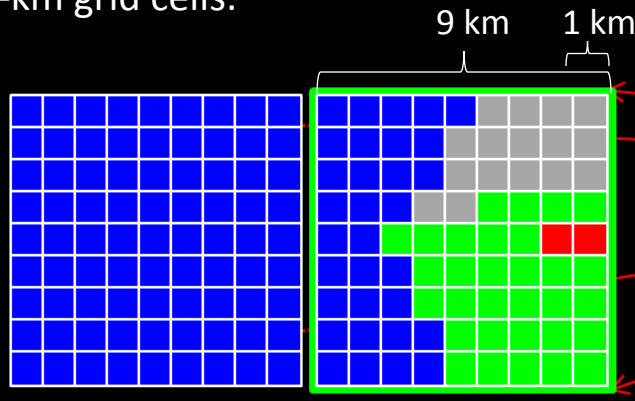


$$\theta_{\ln} = \ln\left(\frac{\theta_{sat} - \theta_{wpsat}}{100 - \theta_{wpsat}} * 100\right)$$

$$\theta_{rescaled} = \frac{\ln(\theta_{\ln})}{\ln(100)} * 95 + 5$$

L4_C Land Mask and Vectorization Procedure

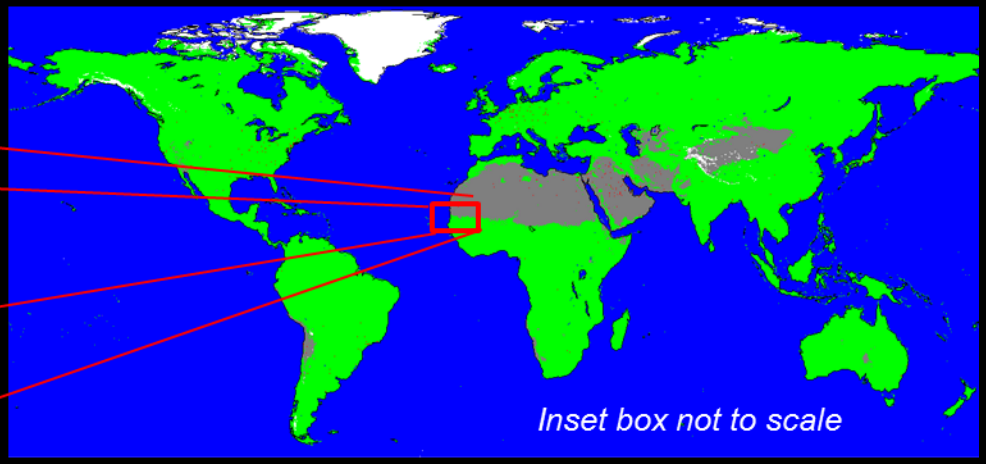
Adjacent in Space
9-km grid cells:



"OUT" cell

"IN" cell

2-D (Grid)

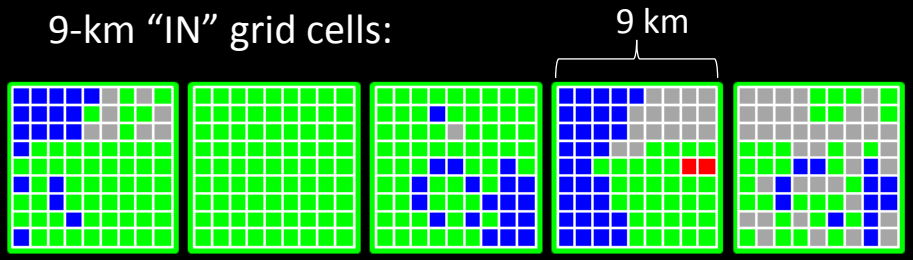


Ice (Not Processed)
Water (Not Processed)
Barren (Not Processed)
Urban (Not Processed)
Vegetated land (Processed)

Send "IN" cells to
Model Step Processor

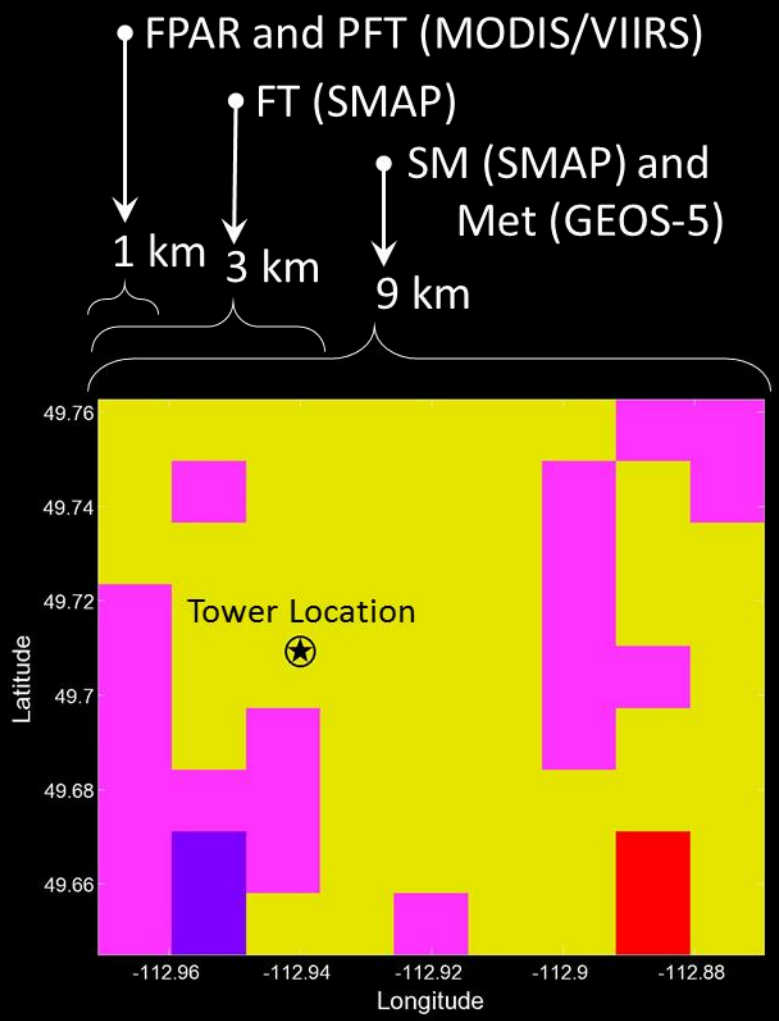
1-D (Vector)

Adjacent in Memory
9-km "IN" grid cells:

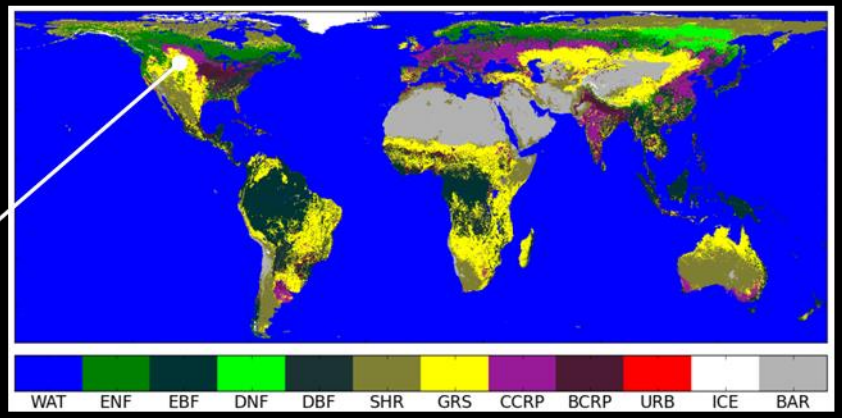


Read multi-resolution input data cells in nested loops [9 km – 3 km – 1 km] then do model step @ 1 km for all global veg. cells.

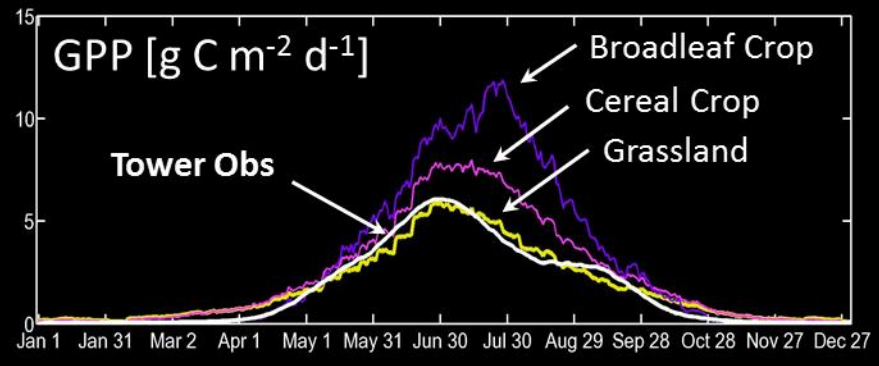
Nested-resolution [1]EASE Grid v2 Processing



MODIS (MCD12Q1) 1 km EG v2
Plant Functional Type Classification



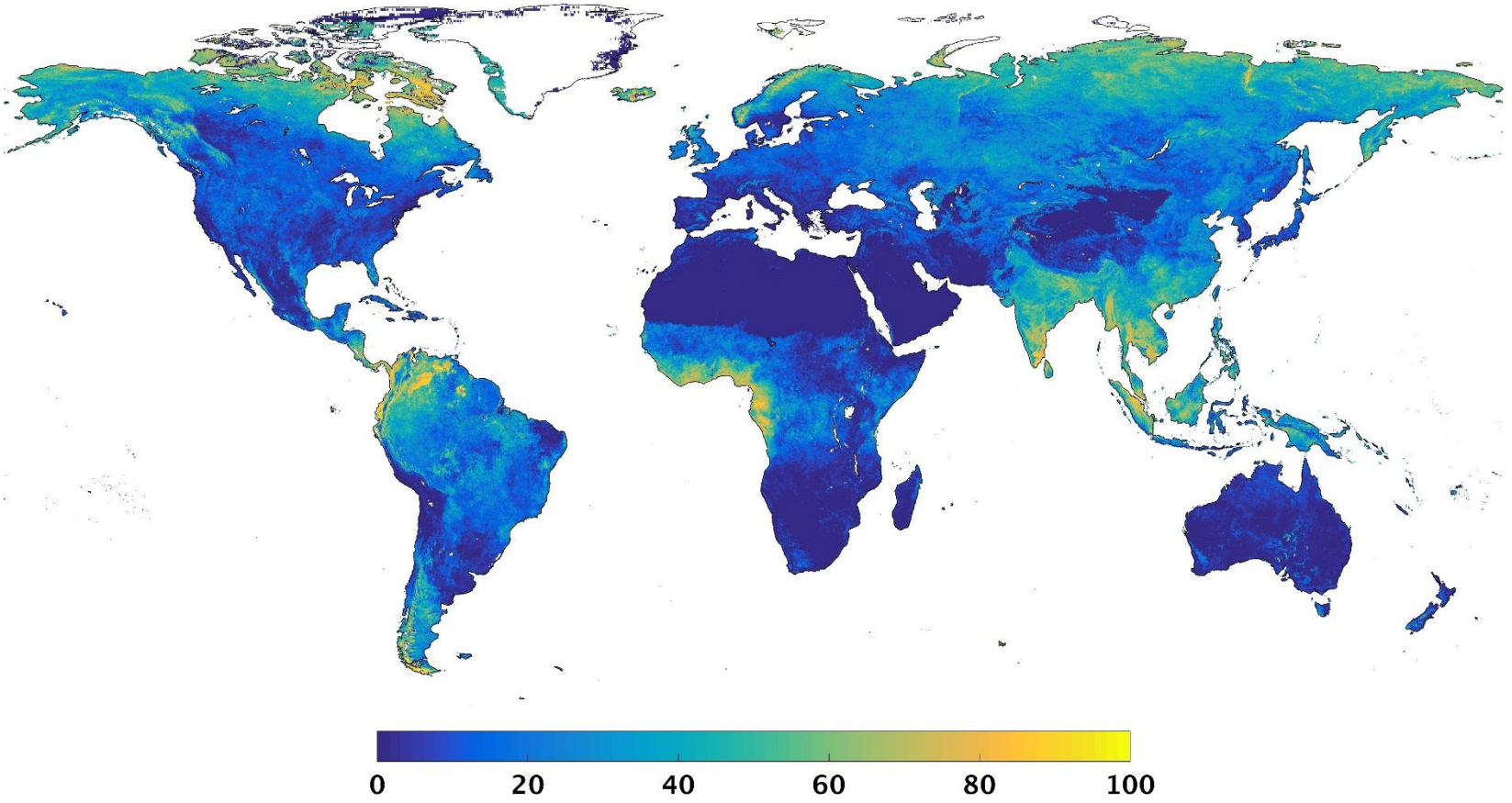
L4C Output 9km x PFT



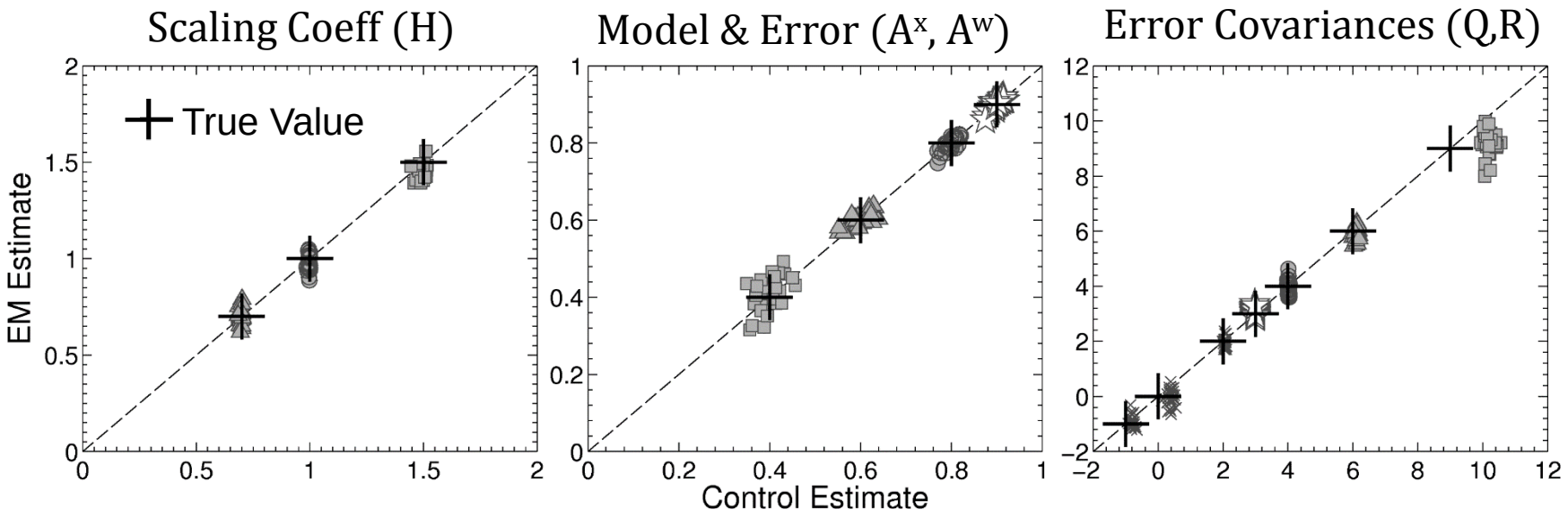
[1]Brodzik, et al., ISPRS Int. J. Geo-Inf. 2012, 1, 1, 32-45; doi:10.3390/ijgi1010032

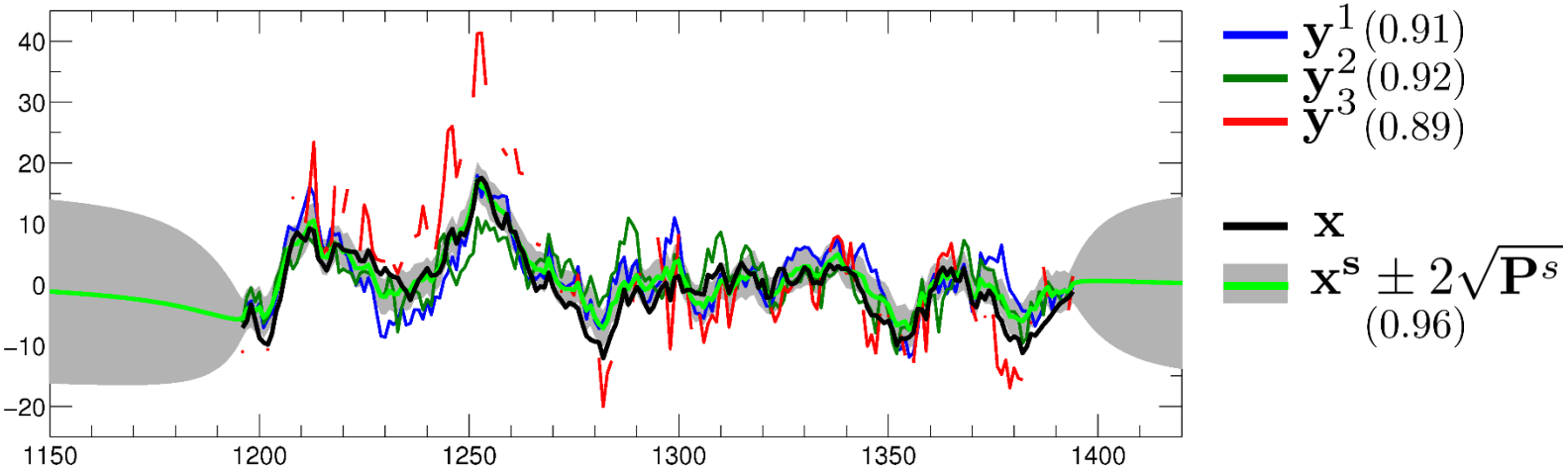
FPAR Climatology Replacement

Percentage of Grid Cells with > 50 % FPAR Clim Fill
(L4_C Vb1010 April 13-Dec 31, 2015)

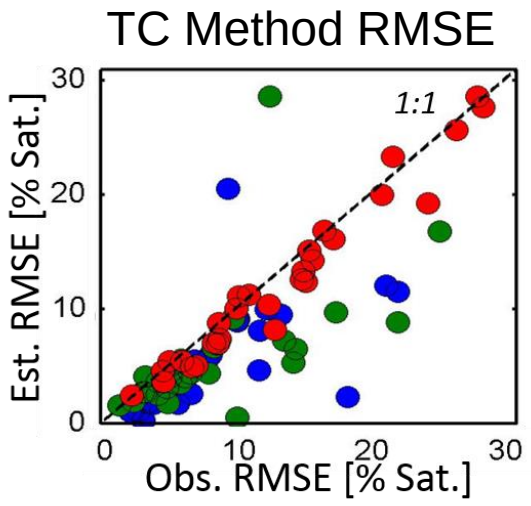


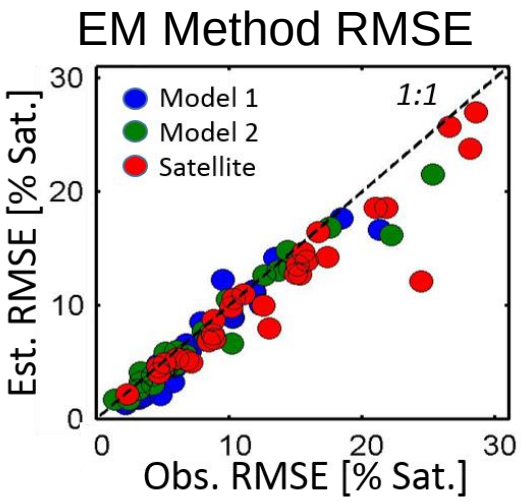
EM & Kalman Smoother Simulation Results

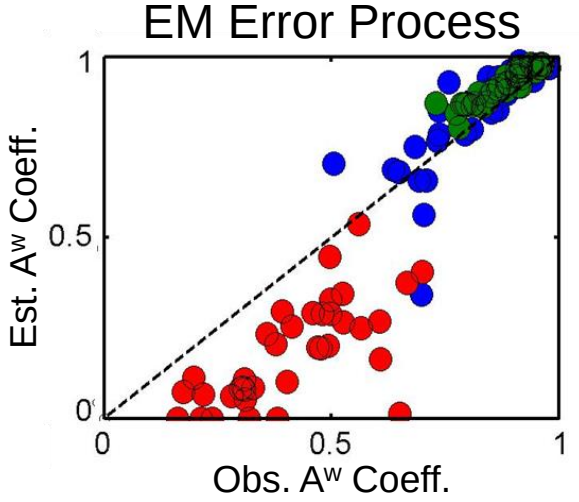


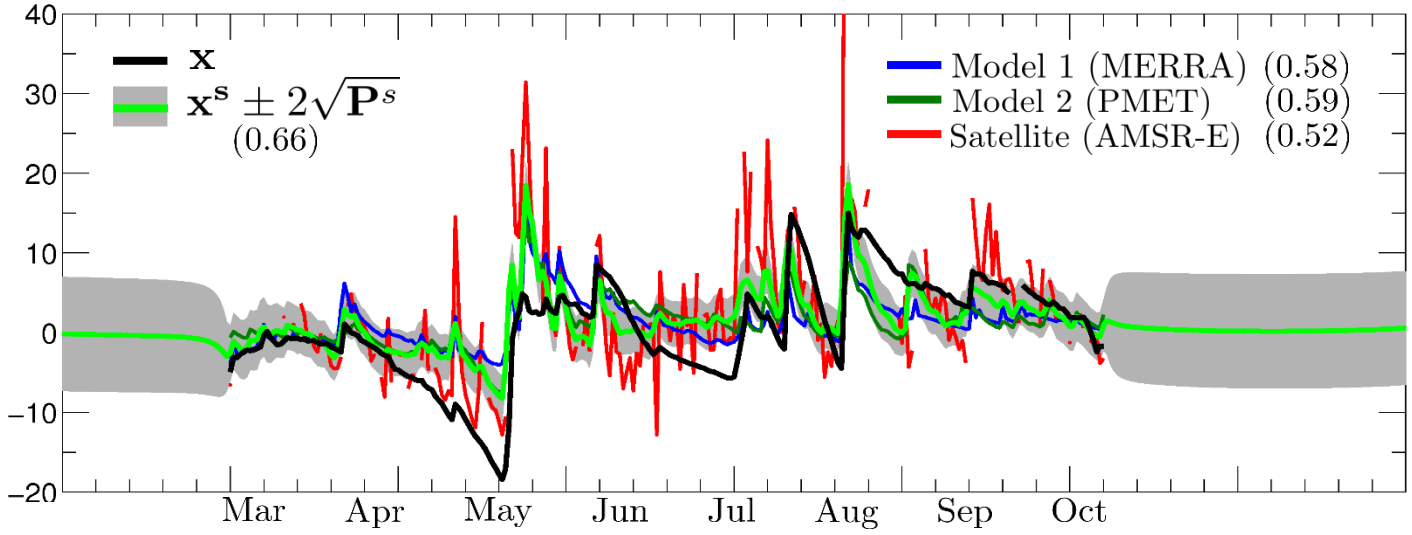


EM & Kalman Smoother Soil Moisture Results



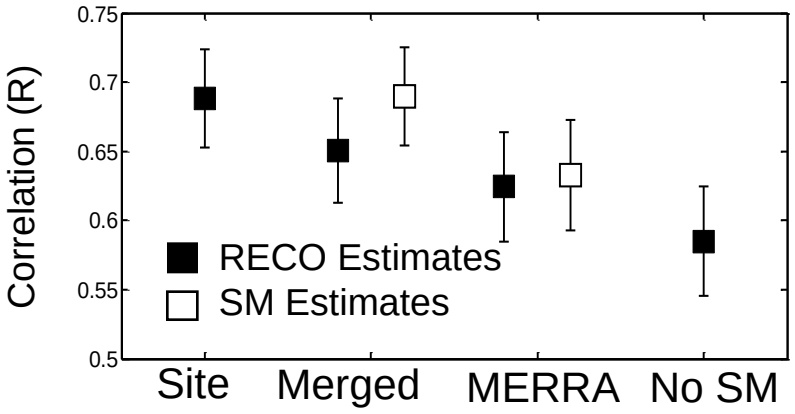




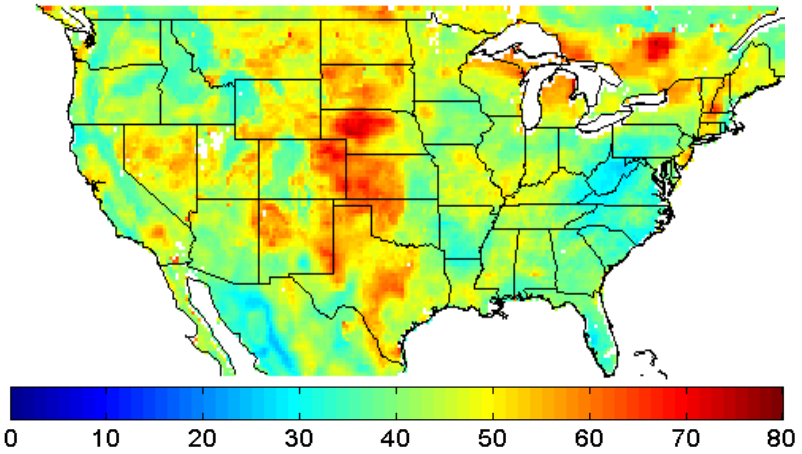


Evaluating Soil Moisture Information for Ecosystem Respiration

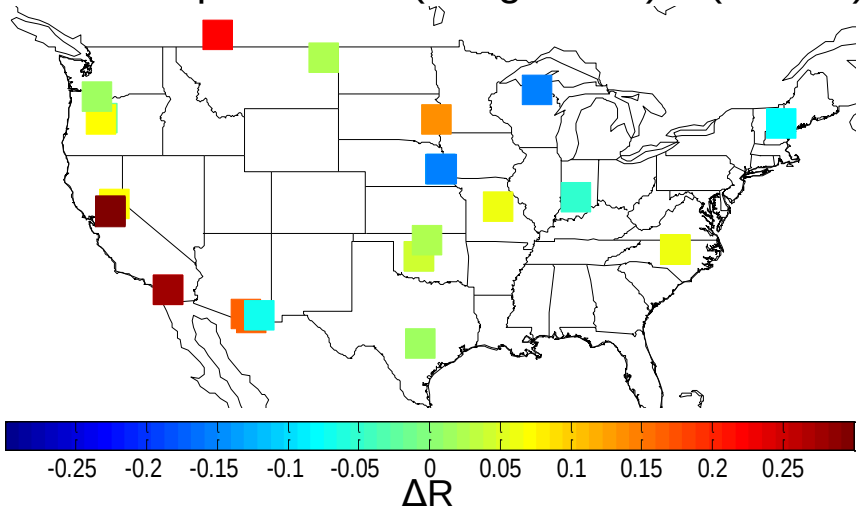
Overall RECO Improvement



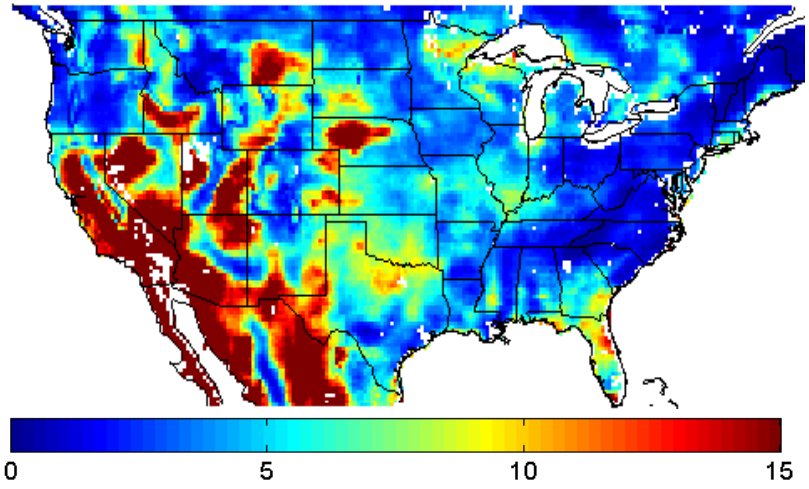
Merged SM RMSE Improvement [%]



RECO Improvement (Merged SM) – (No SM)

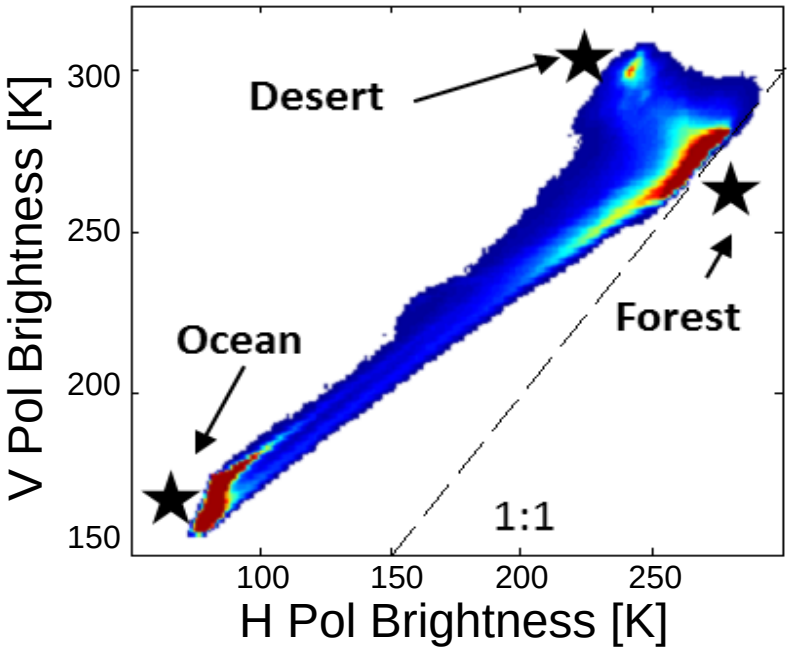


RECO RMSE Improvement [%]



Separating Temperature and Emissivity

Brightness Observations:



Emissivity Model: